BASIC SEWAGE TREATMENT OPERATION

1974

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Ontario

Ministry
of the
Environment

BASIC SEWAGE TREATMENT OPERATION

Training & Licensing Section
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Other courses and workshops offered
by the Training and Licensing Section,
Ministry of the Environment,
include:

Activated Sludge Process
Analyses and Interpretation Workshop

Basic Gas Chlorination Workshop

Basic Water Treatment Operation Course

BEHAVIORAL OBJECTIVE APPROACH TO TRAINING *(BOAT)*

The behavioral (performance) objectives are designed to tell the operator, or trainee, what he will have to know and do in order to complete the course successfully. At the same time, it tells the instructor what he *must* teach, describe, or demonstrate so that the trainee will reach his goal--not what he would *like* to teach.

WHAT IS BOAT?

BOAT is a method of training which states briefly and clearly what the performance of a trainee should be upon completion of a learning period. The objectives are set down at the beginning of each topic so that both the trainee and instructor know what must be done. To verify successful completion, tests are given under conditions as similar as possible to actual on-the-job working conditions. If the test requires an actual "hands-on" performance, the trainee will be tested accordingly.

Objectives serve other purposes as well: they enable the operator to determine how well he is doing on a particular topic, and they also enable the instructor to organize his time for maximum efficiency.

LEVEL OF COMPETENCE

Each topic has stated objectives which must be presented to the trainee at the course. To fulfill the Basic Sewage Treatment Operation course requirements, trainee must achieve a minimum average of 70% on all topics (written, oral, and hands-on testing).

ACKNOWLEDGEMENTS

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1974

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INTRODUCTION

The *Basic Sewage Treatment Operation* course covers five days at the Ministry of the Environment training facilities. The course consists of lecture-discussions on the operation of a sewage treatment plant.

The principal objective of the course is to introduce the operator to the fundamentals of sewage plant operation. The lesson objectives are clearly indicated at the beginning of each topic, and tell the operator exactly what he should know or do after having covered that topic. The operator, or trainee, is expected to reach a minimum level of competence of 70% for the course.

This is a working course in which each person will be expected to take an active part in subject discussions and to acquire as much practical knowledge as possible from the lectures and from the demonstrations presented during the course.

January, 1974

Jacques L. Bourque, Supervisor
Training & Licensing Section
Sanitary Engineering Branch

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 1

SEWAGE CHARACTERISTICS

OBJECTIVES:

Trainee will be able to:

1. Identify the three sources of municipal sewage: domestic wastes, industrial wastes, and commercial wastes.

2. Define:

   - raw sewage
   - primary effluent
   - mixed liquor
   - secondary effluent
   - final or plant effluent
   - infiltration
   - hydraulic loads
   - suspended solids
   - dissolved solids
   - total solids
   - inorganic solids
   - organic solids
   - sewage strength
   - BOD

3. Provide an estimate of the percent of BOD normally removed in a primary treatment plant; in a secondary treatment plant.

4. Provide an estimate of the percent of suspended solids normally removed in a primary treatment plant; in a secondary treatment plant.

5. Explain the importance of nitrogen and phosphorus in sewage treatment.

6. Explain the effect of nitrogen and phosphorus on receiving waters.

SEWAGE CHARACTERISTICS

The adequate treatment of sewage is one of the most important responsibilities of municipalities.

In the 19th Century, several large European cities built closed conduits or pipes for collecting human wastes when the use of streets as open sewers created intolerable living conditions. The discharge of these wastes to nearby rivers and streams soon produced obnoxious odours and ugly conditions.

At about the same time, epidemics were traced to water supplies originating from these rivers and streams. It was discovered that bacteria in the sewage caused diseases such as typhoid fever, dysentery, and cholera. The treatment of sewage thus became a necessity.

Sewage contains countless numbers of living organisms, most of them too small to be visible without the aid of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. Generally, the microscopic living organisms in sewage are *bacteria* and other more complex higher forms of organisms.

An intensive study of bacteria has shown that only a small number of them are disease carriers. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together, the organisms play a major role in *degrading* or *breaking down* organic matter (dead plants and animals and their wastes). By harnessing these organisms

under ideal conditions, as in sewage treatment plants, the breaking down of organic wastes can be speeded up and controlled.

SOURCES OF SEWAGE

In nature, sewage is present as the waste by-product of human and animal life. Man has added to this the waste products of industrial and commercial activity. So the composition of sewage varies widely in both quantity and quality.

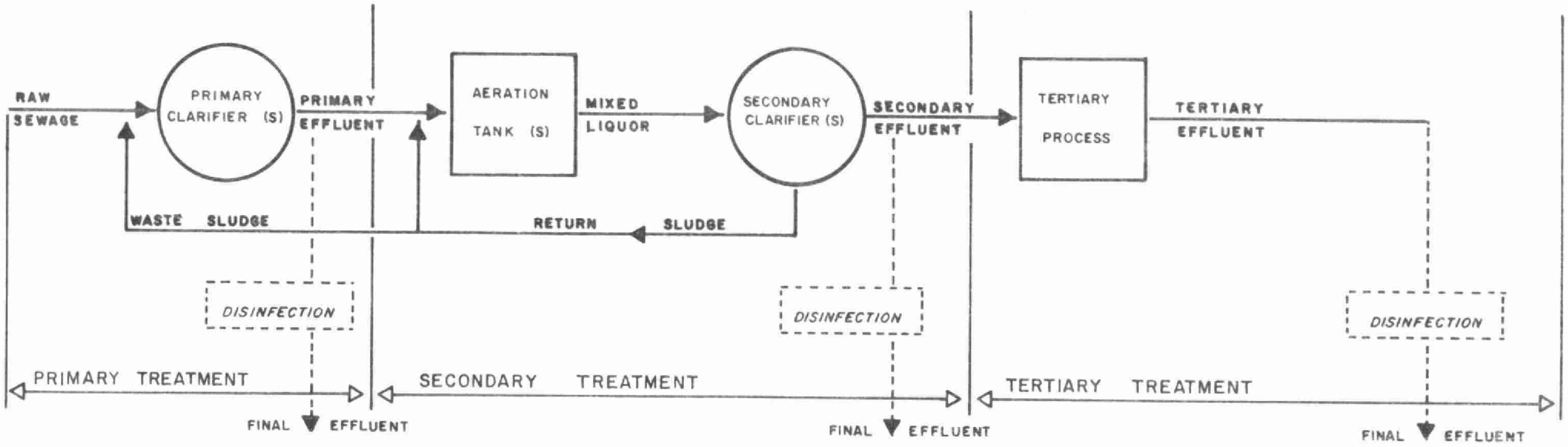
Domestic wastes are those that originate in the bathroom, the kitchen and the laundry room. Once these reach the municipal sewer and combine with any *industrial* and/or *commercial wastes*, they are called *sanitary* or *raw sewage*. Normal sanitary sewage is easily treated in a properly designed sewage treatment plant. Industrial and commercial wastes contained in the sanitary sewage may sometimes be unacceptable for treatment in a municipal sewage plant. In these cases, they must be pre-treated before they are discharged into the sewers.

Figure 1-1 is a schematic diagram of a typical conventional activated sludge plant. *Primary treatment* is used to remove settleable solids from the raw sewage entering the primary clarifiers. The liquid leaving these tanks, called *primary effluent*, may then be disinfected and discharged to a watercourse or directed to aeration tanks, the first stage of *secondary (biological) treatment*. The organic matter in the primary effluent serves as food for large numbers of organisms *(activated sludge)* in these tanks. With adequate oxygen, the organisms use the food for energy and reproduction.

The contents of the aeration tanks, called

FIGURE № 1-1

TYPICAL SEWAGE TREATMENT PLANT



REMOVAL OF B.O.D. & S.S.	B. O. D.		SUSPENDED SOLIDS (S.S.)	
	% Removed	Effluent mg/l	% Removed	Effluent mg/l
PRIMARY PLANT	30 – 40	90 — 150	40 — 60	100 — 150
SECONDAY PLANT	95	15	90 — 95	15
TERTIARY PLANT	98	5	98	5

mixed liquor, then flow into secondary clarifiers where the organisms are allowed to settle and the clear liquid *(secondary effluent)* is either disinfected and discharged, or directed to a *tertiary treatment* process. The settled activated sludge is returned to the aeration tank for re-use, with waste sludge directed to the primary clarifiers. Tertiary treatment further removes solids and organic matter, using processes such as *lagooning*, *filtration*, or chemical treatment and *clarification*. Before being discharged to any stream or waterway, the effluent is always treated with chlorine or some other disinfectant to destroy any remaining disease-causing bacteria. *Regardless of the amount of treatment given the sewage, the liquid leaving the plant is called the final or plant effluent.* Chemicals may be added to the sewage ahead of the primary clarifiers, directly into the aeration tanks, or ahead of the tertiary process in order to remove phosphorus.

QUANTITY OF SEWAGE

In addition to carrying domestic, industrial and commercial wastes, the sanitary sewers may receive large quantities of water from rain and street washings. Water in the ground may also enter sewers through broken and poorly constructed sewer pipes and direct storm drain connections. This is called *infiltration*. Although older sewer systems may collect sanitary sewage and storm water in a single sewer, present policy requires the separate collection of each, since a treatment plant must be designed according to the total flows reaching it. It would be uneconomical to construct a large plant to treat immense quantities of very dilute sewage which only arrive during rainy periods.

The total quantity of sewage reaching the plant is called the *hydraulic load*, varying from hour to hour

and day to day. Normally, daily flows will range between 70 and 130 percent of the water consumption. This percentage will rise if the entry of ground and surface water is a major factor. It will go down due to lawn watering, car washing, hydrant flushing and many other domestic and industrial uses from which the used water is not directed to the sanitary sewer system. An average municipality without large industrial sewage contributors will produce approximately 100 gallons of sewage per capita (person) per day (gpcd). Small rural municipalities and major cities will produce approximately 50 and 100 gpcd, respectively. *Solids account for less than 0.1 of 1 percent by weight of the total sewage flow. The remaining 99.9 percent is water, which carries the solids through the sewer pipes.*

QUALITY OF SEWAGE

A treatment plant removes undesirable materials from sewage, making it acceptable for discharge to lakes or streams. *In so doing, the bacteriological, physical, and chemical characteristics of the sewage are changed.* These changes can best be seen by comparing the characteristics of the raw sewage, primary effluent, secondary effluent, and final effluent of a treatment plant.

Bacteriological Characteristics

Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. Some are harmful to humans and others are not. Complete secondary treatment reduces these numbers by 80 to 95 percent, with effluent chlorination increasing the percentage "kill" to 99.9 percent or better. The highest reductions are generally achieved only when the treatment plant is operating efficiently.

Physical Characteristics

The physical characteristics of sewage include *temperature, turbidity, colour* and *odour*. Table 1-1 compares the physical changes which take place through a typical treatment plant.

TABLE NO. 1 - 1

	TEMPERATURE	TURBIDITY	COLOUR	ODOUR
Raw Sewage	generally warm	high in solids	milky-grey to black	musty to sulphurous
Primary Effluent	lower temperature	fine nonsettle-able solids	greyish to colourless	musty to sulphurous
Secondary Effluent	lower temperature	no visible solids	clear colourless	fresh

The temperature of raw sewage will vary, depending on the source of water supply for the municipality. However, the resultant raw sewage is always somewhat warmer than the water supply. As the sewage passes through the treatment plant, the temperature decreases. The higher the sewage temperature, the faster the decomposition and the better the settleability.

Raw sewage is highly turbid, containing many different types of solids such as paper, rags, garbage, feces, sand and silt. Primary effluent will contain finely suspended and floating matter which can be removed by biological treatment, to produce a clear, colourless secondary effluent.

The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposes sewage is dark, sometimes black in colour with

a sulphurous odour. Normal sewage smells musty but not unpleasant. Primary effluent will be similar to raw sewage except that a large portion of the solids has been removed. The secondary effluent of a properly operated biological treatment plant will be clear and colourless with a fresh odour. Effluent chlorination does not affect temperature, turbidity or colour. It will, however, produce a fresh chlorine odour.

Chemical Characteristics

Chemically, sewage is composed of a great many inorganic and organic solids which are carried in water. The sewage may also contain dissolved gases and living organisms. Inorganic or *fixed* substances are inert and generally will not decay or burn. On the other hand, organic materials will decompose and are sometimes called *volatile matter* since they will burn when heated to high temperature.

Solids

Inorganic and organic substances which can be seen in the sewage are known as *suspended solids.* These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that are not seen are classified as *dissolved solids. Total solids,* as the name implies, include all of the solids contained in sewage.

Inorganic solids consist of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. *Hard water produces a higher mineral content in the sewage.* Some of the more common

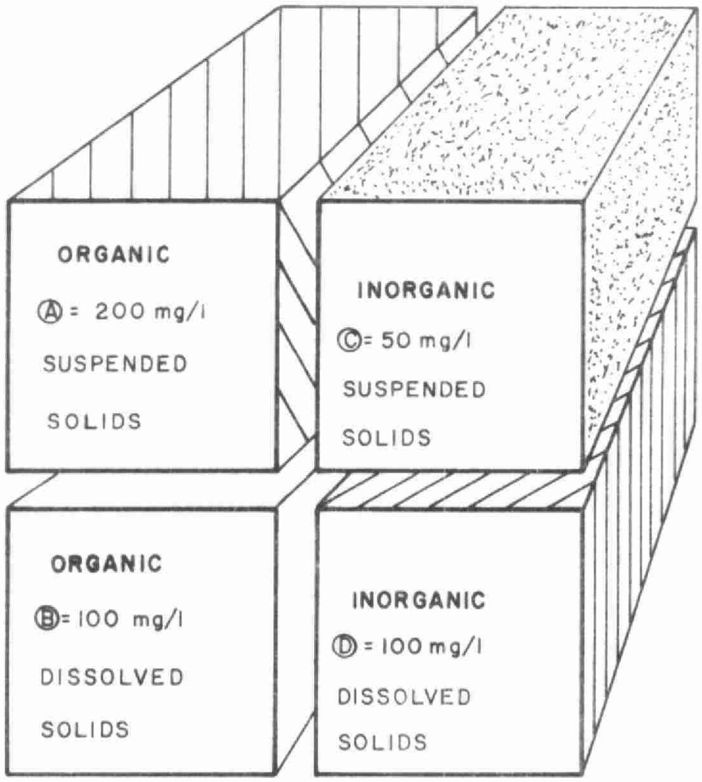
minerals and salts found in sewage are sulphates, carbonates, bicarbonates and chlorides of calcium, magnesium, sodium, potassium and iron. These are beneficial to the organisms and not normally troublesome in a sewage treatment process.

Organic solids are generally of animal or vegetable origin. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorus. The principle groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms, resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous substances such as hydrogen sulphide gas and various sulphate compounds. These waste products are in turn used by plant and animal life in their growth processes. The cycles of life, death and decay involve carbon, nitrogen and sulphur. These basic elements recycle in our environment where the products of death and decay become the foods for plant and animal life.

Quantities or concentrations of solids, whether inorganic or organic, will differ from hour to hour and from sewage plant to sewage plant. Typical concentrations of solids in a medium strength raw sewage are shown graphically in Figure 1-2. Sewage strength can be defined as the amount of organic material present in the sewage. The successful operation of a biological treatment plant depends, to a great extent, upon this sewage strength because it provides the food for the organisms.

FIGURE Nº 1-2

COMPOSITION OF SOLIDS IN A MEDIUM STRENGTH RAW SEWAGE



TOTAL SOLIDS = A + B + C + D = 200 + 100 + 50 + 100 = 450 mg/l

TOTAL ORGANIC SOLIDS = A + B = 200 + 100 = 300 mg/l

TOTAL INORGANIC SOLIDS = C + D = 50 + 100 mg/l

TOTAL SUSPENDED SOLIDS = A + C = 200 + 50 = 250 mg/l

TOTAL DISSOLVED SOLIDS = B + D = 100 + 100 = 200 mg/l

The total solids in a sewage consist of all suspended and dissolved inorganic and organic materials. From Figure 1-2 it can be seen that the concentration of total solids in medium strength sewage is approximately 450 mg/l. This consists of 300 mg/l organic matter in addition to 150 mg/l inorganic matter. The same total solids figure is arrived at by adding the suspended and dissolved solids (shown as 250 mg/l and 200 mg/l respectively).

When storm or groundwater finds its way into the sewage, the relationships of these solids may change significantly. Similarly, industrial and commercial wastes may increase the solids content with definite variations in the strength of the sewage. Also, sewage will vary widely in both composition and volume from hour to hour, depending upon changes in community activities. Sewage is likely to be at its maximum strength and flow during the daytime and at its minimum during the night hours. On weekends and holidays, flows and strengths are often reduced due to slower communal activity. Therefore, data on sewage can never be applied equally to all sewages at all times.

A primary sewage treatment plant will normally reduce suspended solids by 40 to 60%. Complete secondary treatment generally will remove 90 to 95% of the suspended solids, producing a final effluent with suspended solids less than 15 mg/l.

BOD

The standard for determining the organic strength of sewage is called the *Biochemical Oxygen Demand* or *BOD*. This is simply a measure of the oxygen used in decomposing organic matter. Normally, the test

is carried out in the laboratory at a temperature of 20°C over a period of five days with the result being reported in ppm or mg/l 5-day BOD (BOD_5).

Raw sanitary sewage will normally have a BOD_5 ranging between 150 mg/l and 250 mg/l. Industrial and commercial wastes will affect this, however. *A primary sewage treatment plant will normally reduce BOD by 30-40%. Complete secondary treatment generally will remove 95% of the BOD, producing a final effluent with a BOD less than 15 mg/l.*

Dissolved Gases

Sewage contains small and varying concentrations of dissolved gases. Among the most important of these is *oxygen*, present in the original water supply and also dissolved from air in contact with the surface of flowing sewage. In addition to dissolved oxygen, sewage may contain other gases such as carbon dioxide, ammonia and hydrogen sulphide (the products of decomposition) as well as nitrogen dissolved from the atmosphere. These gases, although small in amount, can indicate the degree of sewage decomposition.

Nutrients

Nitrogen and *phosphorus* are two important nutrients in the operation of a sewage treatment plant and in the receiving watercourse. In the sewage plant they are essential for the growth of organisms involved in the decomposition of organic matter. Sanitary sewage normally contains an excess of both nitrogen and phosphorus. This excess, when discharged into the plant effluent, acts as an undesirable fertilizer, promoting the growth of algae in receiving waters.

Nitrogen is present in wastes in the form of ammonia, nitrite, nitrate, and organic nitrogen, each representing a different stage of waste decomposition. *Total phosphorus* is composed of a number of organic and inorganic compounds which may be present in a soluble or insoluble form. These compounds can be grouped into three categories: namely, orthophosphorus, organic phosphorus and polyphosphorus.

Table 1-2 summarizes the ranges of *typical* nitrogen and phosphorus analyses for a conventional secondary sewage treatment plant.

TABLE NO. 1 - 2

	NITROGEN				PHOSPHORUS	
	Ammonia	Organic	Nitrite	Nitrate	Total	Soluble
Raw Sewage	15-50	25-85	less than 0.1	less than 0.5	6-12	4-6
Primary Effluent	15-50	25-85	less than 0.1	less than 0.5	4-8	4-6
Secondary Effluent	0-1	5-20	less than 5.0	greater than 10	3-6	2-5

In conventional sewage treatment very little nitrogen and phosphorus are removed, although they may change form chemically. Where high phosphorus removals were noted at activated sludge plants, the raw sewage usually contained aluminum or iron from industrial sources. By adding aluminum, iron or calcium compounds at the treatment plant, total phosphorus can be reduced to less than 1.0 mg/l in the final effluent.

SUBJECT:

BASIC SEWAGE TREATMENT OPERATION

TOPIC: 2

MICROBIOLOGY OF SEWAGE

OBJECTIVES:

Trainee will be able to:

1. Explain the following characteristics of a bacterial cell:

   - shape
   - arrangement
   - size

2. Explain the function of:

   - bacterial slime layer
   - extracellular enzymes
   - intracellular enzymes

3. Define (describe) in general terms the reproduction of bacteria as it relates to sewage treatment.

4. Explain how the temperature, oxygen, and pH affect the bacterial growth in sewage treatment.

5. Describe the digestion or metabolism of sludge.

MICROBIOLOGY OF SEWAGE

Sewage is composed of water, organic and inorganic material, and living organisms (bacteria). The main objectives of a sewage disposal system are:

1. to remove organic material (dissolved or suspended)
2. to eliminate disease producing agents

Some human diseases are transferred from man to man by his own fecal discharges. In the past, contaminated water has played a large role in the spread of disease. However, today's methods of sewage treatment and disinfection of plant effluent destroy the disease causing bacteria in these wastes and prevent them from entering the waterways.

Furthermore, the sewage treatment system prevents pollution by transforming dissolved and suspended organic materials into:

1. stable mineral compounds
2. biological cell contents

Bacteria are the principle agents active in these processes. They are unicellular plant organisms; they grow, reproduce, respire, take in food, give off wastes, and respond to stimuli.

Structure of Bacteria:

The structure of a bacterial cell must be considered in order to understand how the bacteria function in sewage. Bacterial cells may be characterized by their:

1. size
2. shape
3. arrangement

Although there are thousands of different bacteria, the individual one-celled bacterium have one of two general structural forms (or shapes) (Fig. 2-1):

1. spherical, or
2. rod-shaped

These two structural forms can be observed in the following arrangements:

1. individual cells
2. pairs of cells (diplo)
3. chains of cells
4. clusters of cells

Figure 2-1 shows the shapes and arrangement of bacterial cells.

Sewage bacteria are extremely small. The majority measure approximately 0.00002 inches in thickness and 0.0001 inches in length. A volume of one cubic inch is sufficient to contain approximately nine trillion (9,000,000,000,000) bacteria (Pelczar and Reid, 1965). Also, one drop of water is capable of holding 1,000,000 bacteria. These examples give us an indication of the smallness of these living organisms. *An important consequence of the smallness of bacterial cells is that the ratio of surface area to volume is exceedingly high.*

Each bacterium has a cell wall which surrounds a substance known as *protoplasm* (see Fig. 2-2). This protoplasm contains all that is required to sustain cell life and includes numerous enzymes produced in the protoplasm.

Figure 2-1

SHAPES AND ARRANGEMENT OF BACTERIAL CELLS.

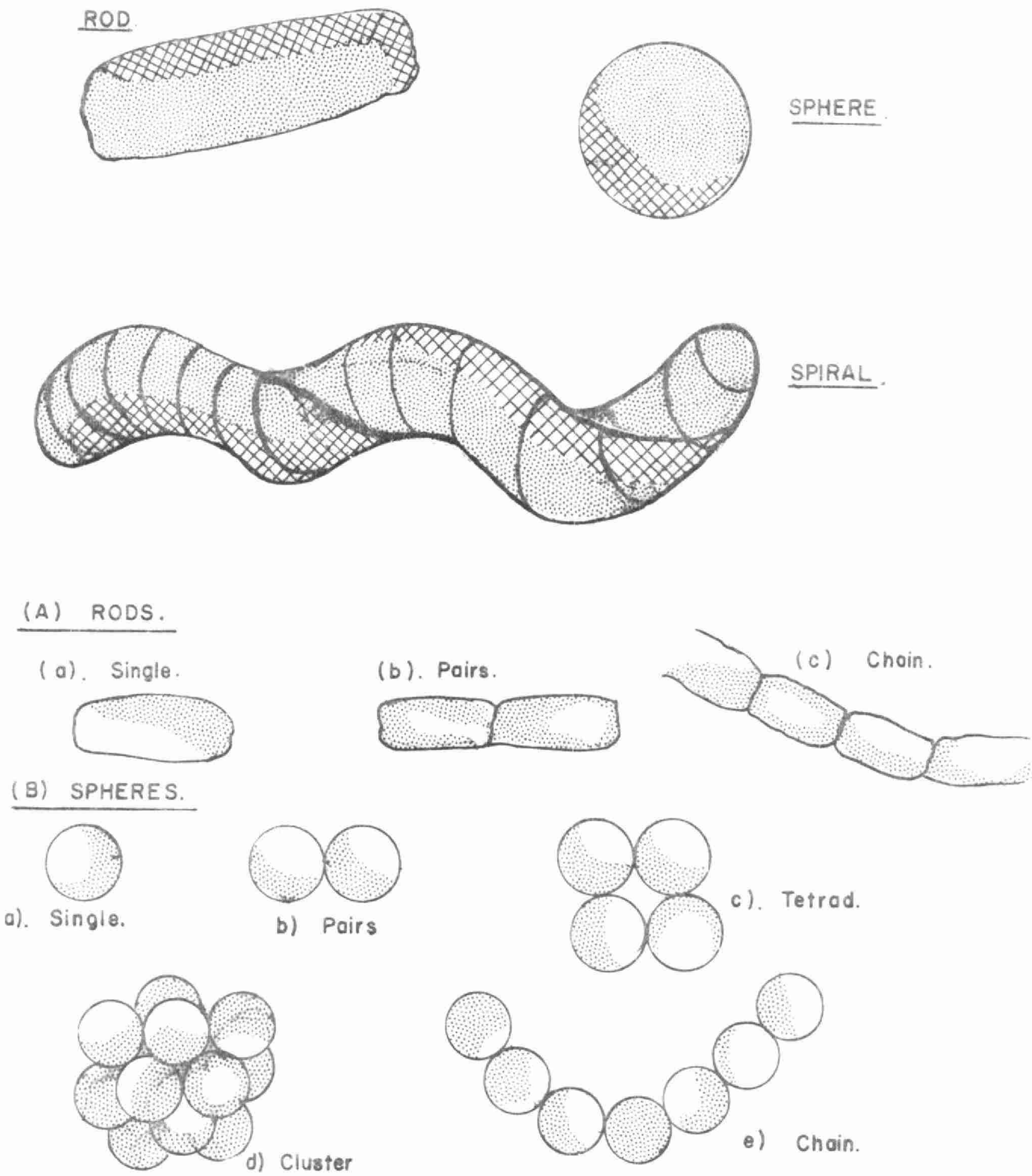
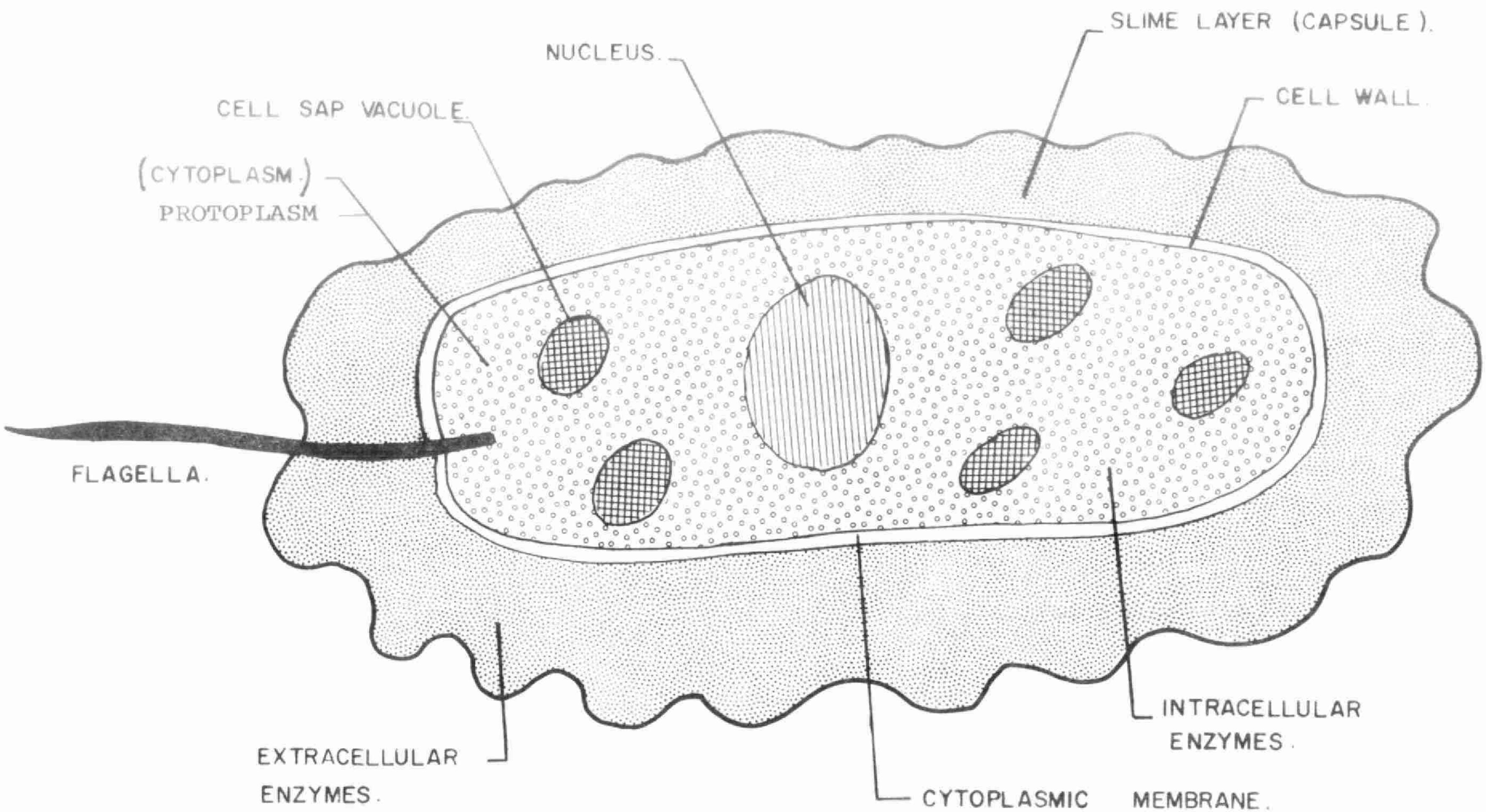


Figure 2-2

SCHEMATIC DIAGRAM OF A BACTERIAL CELL.



Reproduction of Bacteria

Reproduction of bacteria is a process whereby one cell divides in half, producing two new cells. This process is called *MULTIPLICATION BY DIVISION.*

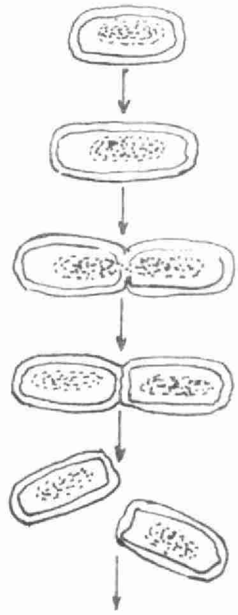


Figure 2-3 Bacteria - Reproduction by Division

Thus, if we start with a single bacterium, the increase in population growth is by geometric progression: 1 ⟶ 2 ⟶ 4 ⟶ 8 ⟶ 16 ⟶ 32 etc. (see Fig. 2-4)

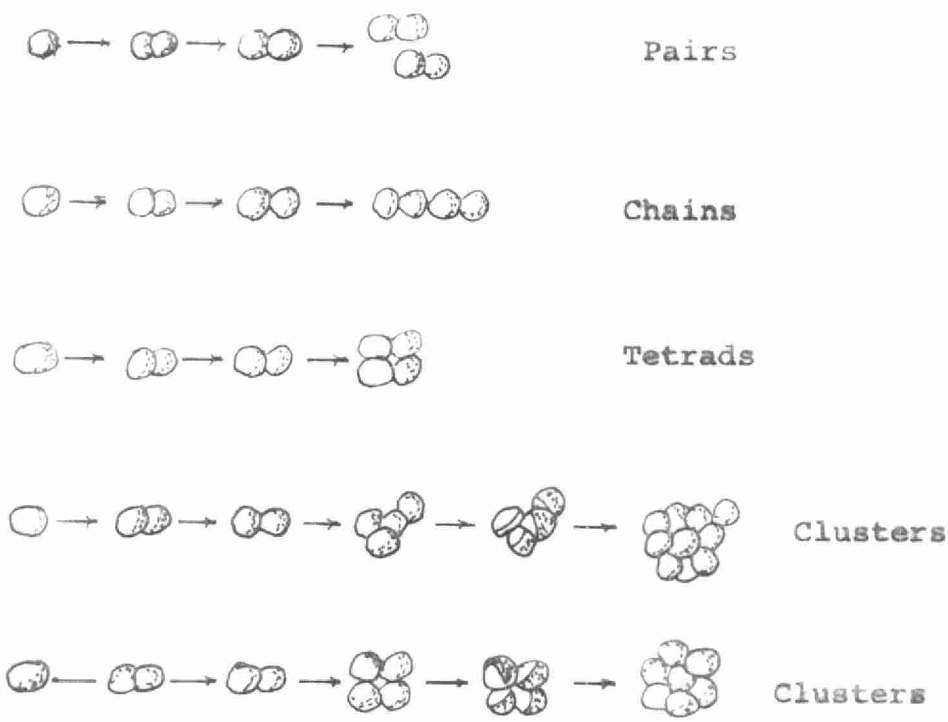


Figure 2-4 Bacteria - Multiplication Showing Patterns

The time interval required for a cell to divide can be anywhere from thirty minutes to several hours, depending on the type of bacteria and the environmental conditions. This fast rate of reproduction may be halted by:

1. a build-up of the bacteria's toxic waste products (organic acids, etc)
2. exhaustion of the food supply
3. unfavourable environmental conditions

It has been calculated that if a bacterial cell continued to multiply at its maximum growth rate, the combined mass would be equal to that of the sun within a year.

Activity or Growth of Bacteria

Virtually every organic compound occuring naturally or produced biologically can be utilized as food by some bacteria.

Bacterial growth is affected enormously by the following physical conditions existing in its environment:

1. temperature
2. free oxygen
3. pH
4. food supply

All growth processes depend on chemical reactions. Since the rate of these reactions is influenced by *temperature*, therefore bacterial growth is profoundly influenced by *temperature*. The ideal temperature for the growth of most bacteria found in sewage is 95 - 100°F (approximately 37°C).

Bacteria also display a wide variety of responses to *free oxygen.*

1. *AEROBIC* bacteria grow in the presence of free oxygen
2. *ANAEROBIC* bacteria grow in the absence of free oxygen
3. *FACULTATIVE* bacteria grow in either the absence or presence of free oxygen

The *pH of the environment* also affects bacterial growth. For most bacteria, the ideal pH for growth lies between 6.5 and 7.5.

In order for bacteria to maintain life, they must have sufficient and constant *food supply.* The organic matter contained in sewage is the main source of food.

These four factors affect the efficiency of the sewage treatment process. For example, in the activated sludge tank, the sewage is supplied with large amounts of oxygen for consumption by aerobic bacteria. This activated sludge process is subject to seasonal temperature changes. Thus, in winter, the bacterial activity slows down. However, sewage at lower temperatures can hold more oxygen. Therefore oxygen supply to the bacteria increases in winter. Thus, the decrease in activity due to lower liquid temperatures in winter is offset by the increase in activity due to the increase in oxygen supplied to the bacteria.

In the anaerobic digestion process, oxygen would interfere with the activity of anaerobic bacteria and is therefore not supplied. In this process the bacterial waste products are organic acids and methane gas (Chart 2-2). These volatile acids, unless used up quickly by the methane forming bacteria, will increase

the acidity and lower the pH of the digester contents, slowing down bacterial activity. For optimum growth or activity, the temperature of the anaerobic digester should be maintained at approximately 95°F (37°C).

Enzymes

An enzyme is an organic catalyst. It is secreted by the living bacterial cells and its function is to produce chemical changes in organic matter (sewage).

It has been estimated that a single bacterium contains several hundred distinct enzymes. It is important to note that enzymes are capable of performing all the chemical changes associated with life processes. Any impairment of their activity is reflected by some change in the cell, even to the point of death.

Bacterial enzymes are made up of organic and inorganic substances that *increase* the speed at which a chemical reaction takes place. Each enzyme is specific for one chemical process. There are two types of bacterial enzymes:

1. extracellular enzymes
2. intracellular enzymes

Extracellular enzymes are excreted through the cell wall and function outside the cell. Their main task is to break down the organic compounds into soluble particles so that these may be readily brought through the cell wall into the cell for nourishment. Intracellular enzymes are mainly associated with metabolism inside the cell.

Since enzymes are specific to a particular biochemical change, the bacterium must produce a separate enzyme for each chemical reaction.

Metabolism

Metabolism is defined as the feeding habits of bacteria through which:

1. cells are formed
2. energy for life is obtained
3. they eliminate their wastes

Raw sewage is generally composed of water, suspended solids and other soluble organic and inorganic substances. Initial sedimentation of suspended solids takes place in the primary settling tank.

The unsettled portion of the sewage enters the activated sludge tank where floc formation and aerobic metabolism occurs. Bacteria produce a slime or gum which literally holds bacteria cells together. As the cell mass or floc builds up, it is then allowed to settle to the bottom in the final settling tank to form *sludge*. The sludge is either recycled through the aerobic process or drawn off to the anaerobic digester. Essentially, the floc formation removes bacterial cells as waste material. A simplified explanation of the activated sludge or aerobic metabolism is as follows:

AEROBIC METABOLISM IN THE ACTIVATED SLUDGE TANKS

$$\text{SEWAGE} \xrightarrow[\text{BACTERIAL ENZYMES} \quad \text{ENERGY}]{} \text{CELL CONTENTS} + \text{WASTES}$$

= Proteins	= Sludge (floc)	= CO_2 (carbon dioxide)
= Carbohydrates eg. Toilet paper		= H_2O (water)
= Fats eg. Kitchen grease		
= Soaps		

In the anaerobic digester metabolism occurs as follows:

ANAEROBIC METABOLISM IN ANAEROBIC DIGESTER

$$\text{SLUDGE} \xrightarrow[\text{ENERGY}]{\text{BACTERIAL ENZYMES}} \text{ORGANIC (volatile) ACIDS} \xrightarrow[\text{ENERGY}]{\text{BACTERIAL ENZYMES}} \text{WASTES}$$

=cell contents (bacteria)	=acetic acid eg. vinegar	= methane (CH_4) (gas)
=proteins	=propionic acid	=carbon dioxide (CO_2)
=carbohydrates	=formic acid	
=fats	=butyric acid	
=soaps	=valeric acid	

In both the activated sludge and anaerobic digestion processes the *extracellular enzymes* reduce the size of the larger organic particles to simple soluble substances so the bacterial cell wall can absorb them. Inside the cell, the *intracellular enzymes* react with the absorbed substances to produce new cell structures, energy for life, and wastes which are eliminated. In anaerobic digestion the organic acids should be metabolized as rapidly as they are produced. If not, the pH will drop to levels that will slow the growth of desired bacteria.

The countless numbers of bacteria in the sewage exposing an enormous area of cell surface, and ideal growth conditions causing high metabolic activity, are responsible for the rapid changes in the characteristics of the sewage.

Bacteria and Disease

In the past, contaminated water has played a large role in the spread of disease. When proper water and sewage treatment facilities are installed in a community, the health of its inhabitants is improved noticeably, and their life span is extended.

Many sewage bacteria are normal inhabitants of the intestinal tract of man and animals. Occasionally pathogenic bacteria (disease causing bacteria) are included among them. For example, a disease caused by this type of bacterium is *TYPHOID FEVER;* on the other hand, the *coliform* group of bacteria is a normal inhabitant of the intestine and is not generally harmful to health.

Chlorine, in high enough concentrations, kills all bacteria; its main purpose is to kill disease causing bacteria, thus preventing them from entering the waterways and causing outbreaks of waterborne communicable diseases.

Sewage Sample Analysis

Sewage samples are analyzed to determine the levels of total coliforms, fecal coliforms, fecal streptococcus and, periodically, levels of other bacteria such as pseudomonas and clostridia. The laboratory technique used for this purpose is the *Membrane Filtration Test.* Selective amounts or dilutions of water are filtered by a special apparatus through a membrane filter which prevents the passage of bacteria. The filter is removed from the apparatus and placed in a selective media which allows growth of the bacteria. The filter and media are incubated at the most suitable temperature and growth period for the specific bacteria. The bacteria grow until they form colonies. Each colony develops from the multiplication of a single bacterial cell.

The number of colonies of bacteria appearing on the filter are counted under a microscope. The final result is reported on the basis of 100 ml of the sample tested (Bacteriological report page 2-16).

Note: The period of time between the collection of the sample and its analysis in the laboratory is very critical. *To ensure reliable results samples should arrive at the laboratory ideally within 4 to 8 hours but no later than 24 hours after sampling* and, if at all possible, they should be chilled immediately and kept cool until arrival at the laboratory.

SUMMARY

1. Sewage treatment is biochemical in character and bacteria are the principal active agents in the mineralization of solids and dissolved salts.

2. The mechanism which enables a rapid mineralization of wastes at normal temperature is the enzyme system.

3. Without bacterial activity, the sewage treatment process would require large amounts of energy, e.g. burning sewage in a furnace. This would be very costly.

4. All treatment processes merely cater to bacterial activity.

5. Bacteria are not acting in any special way in sewage treatment, but are merely doing the job for which they are intended.

MAIL ADDRESS
MINISTRY OF THE ENVIRONMENT
LABORATORY BRANCH
P.O. BOX No. 213
REXDALE, ONTARIO

MINISTRY OF THE ENVIRONMENT

LABORATORIES

EXPRESS ADDRESS:
RESOURCES ROAD
HIGHWAY 401 & ISLINGTON AVE.
TORONTO, ONTARIO

Municipality: Clearwater
Source: Municipal W.P.C.P.
Program: Routine Sampling
Date sampled: July 1/73 by: J.C. Doe
Date analysed: Date reported:

Report to: A.B. Masters (Plant Supt.)
Address: 135 Brook Street
Clearwater, Ontario

C	
Bi	
Ba	✓

LAB. NUMBER	SENDER'S NUMBER	SAMPLING POINT LOCATIONS AND TIME	NATURE OF SAMPLE, DANGEROUS CONSTITUENTS, PRESERVATIVES USED, COMPOSITING DATA, ETC.	✓CHECK BELOW IF CHLORINE PRESENT
	07	Final Effluent	10:00 A.M.	✓
		(Sample treated with sodium thiosuphate)		

SEE DIRECTIONS OVER

LAB. NUMBER										

FOR LAB USE ONLY

2-14

INSTRUCTIONS

SAMPLING DIRECTIONS

This form should accompany all samples, with copies included for each laboratory (chemical, bacteriological and biological) to which samples are submitted. Samples for each laboratory should be taken in separate, individually labelled bottles. Suitable bottles are available, on request, from the laboratory shipping department. Phone 248-3027 No charge is made for routine analyses. The sender shall bear all shipping costs.

ALL SAMPLES ARE PERISHABLE Please submit promptly, as early in the week as possible. Keep samples cool, preferably chilled, and away from light. Avoid freezing. Samples may be delivered to the laboratory anytime; at night, or on weekends and holidays, they will be refrigerated.

BACTERIAL STERILE BOTTLES (6 OZ. OR MORE) MUST BE USED. TO ENSURE RELIABLE RESULTS, SAMPLES SHOULD ARRIVE AT THE LABORATORY WITHIN 24 HOURS OF SAMPLING OR BE REFRIGERATED IF DELAY IS UNAVOIDABLE.

For other than routine examinations, please enquire beforehand. Phone 248-3008. DO NOT OPEN THE BOTTLE until all other sampling preparations have been made, then discard the cellophane dam. Samples from taps must be taken only after aerators, screens and hoses, etc., have been removed, and THEN only after the water has been running for two minutes. Samples from open waters must be taken by tying a clean copper wire to the bottle's neck before removing the cap, and then lowering it below the water's surface. Collect samples directly in the sterile bottles provided and NOT BY MEANS OF A DIPPER. While bottle is being filled, hold cap in hand — DO NOT LAY IT DOWN. Do not touch its inner surfaces or the mouth of the bottle with hands or any other object. Always leave an air space in the bottle unless advised otherwise.

CHEMICAL Our standard 32-oz. bottle contains sufficient sample for routine tests only. (Since sludge samples develop gas, leave bottle half-empty). Additional non-routine tests require more sample (2 bottles) and special sampling and handling techniques. Please enquire beforehand. Phone 248-3025.

BIOLOGICAL Any specimens for identification should be refrigerated or preserved in 5% formaldehyde and submitted as soon as possible. Where special biological analyses are desired, sampling procedures are best arranged with the biological staff beforehand. Phone 248-3011.

SAMPLE CLASSIFICATION

A variety of samples is received. To ensure that your samples receive the proper tests, CLASSIFY EACH SAMPLE AND CHOOSE THE ANALYSIS DESIRED, BELOW:

WATER These include samples taken from sources of supply, treatment and distribution systems and waters used for drinking, domestic or industrial purposes.

☐ BACTERIAL Coliform ☐ CHEMICAL—Hardness, Alkalinity Iron, Chlorides, pH ☐ BIOLOGICAL EXAMINATION

SEWAGE AND STREAM Include samples taken from waste discharges, waste collection and treatment systems. To detect pollution, the probable source should be sampled, together with the receiving water, prior to and following entry of the pollution. Describe the type of pollution, and its ingredients, below:

☒ BACTERIAL Coliform ☐ CHEMICAL—Biochemical Oxygen Demand, Suspended Solids or Turbidity ☐ BIOLOGICAL EXAMINATION

SPECIAL ANALYSES

For other than routine determinations, preliminary discussion with laboratory staff facilitates, and often is essential for an appropriate and reliable analysis. Phone 248-3421. Enter below a brief description of the problem which has necessitated the submission of samples, designating the materials sought or suspected of being present.

Describe Problem: ______________________________

MINISTRY OF THE ENVIRONMENT – LABORATORY BRANCH

BACTERIOLOGICAL REPORT

FILE: Town of Clearwater

DATE:	SAMPLED D M Y	ANALYSED D M Y	REPORTED D M Y		
	1 7 73	2 7 73	6 7 73	500001	500001

REPORT TO: Mr. A.B. Masters, Superintendent, W.P.C.P. 135 Brook Street, Clearwater, Ontario

COPY TO: Town Clerk, etc.

PARTICULARS:
LAB NO.
500001 07 Final effluent 10:00 A.M. 500001

RESULTS PER 100 ML:

FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES 50000	COLIFORM BACTERIA 500
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	
FECAL COLIFORMS	PLATE COUNT	BACKGROUND COLONIES	COLIFORM BACTERIA
ENTEROCOCUS	PSEUDOMONAS	CLOSTRIDIUM	

\+ CHLORINE PRESENT
G & L MEANS GREATER THAN & LESS THAN

SUBJECT:

BASIC SEWAGE TREATMENT OPERATION

TOPIC: 3

PRIMARY TREATMENT OF SEWAGE

OBJECTIVES:

Trainee will be able to:

1. Name 3 methods used to direct sewage to the treatment plant.

2. Name at least 3 types of flow control devices in pumping stations. Give 2 advantages of each type.

3. Determine the purpose for installing preliminary treatment devices in sewage treatment plants.

4. Determine the use of different size screens, the frequency of cleaning the screens, the advantages and disadvantages of each.

5. Describe the function of comminutors, barminutors, and other shredding devices.

6. Give at least 3 reasons for installing grit removal units in the process.

7. Name 3 types of grit removal devices and describe their operation.

8. Describe a procedure to follow when determining the amount of grit to be removed, and the frequency of removal.

9. Give at least 4 reasons for pre-aeration of raw sewage.

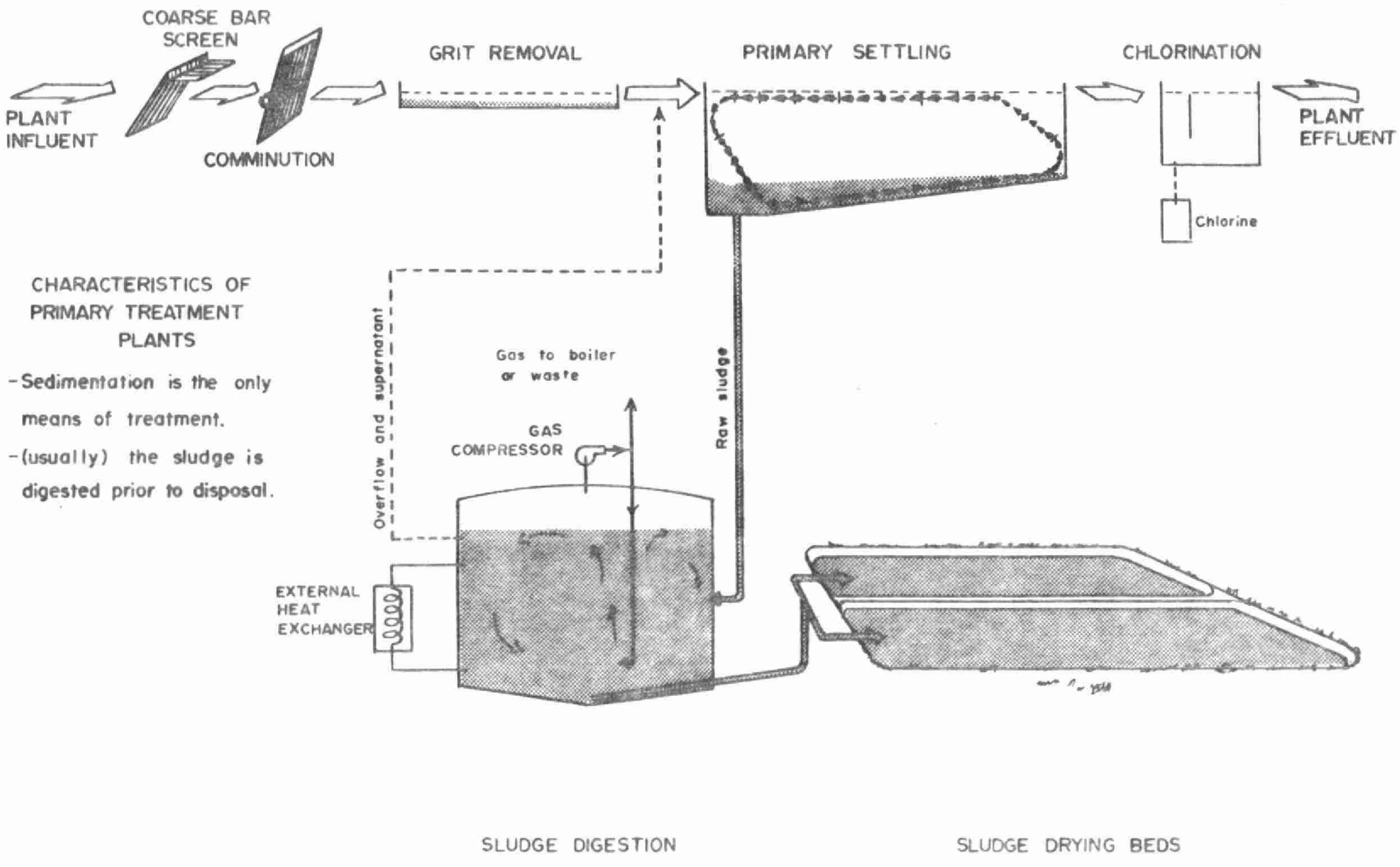
10. Describe the function of the primary clarifier.

11. Describe what corrective measures to take when the sludge being pumped from the clarifier becomes watery after a few minutes of pumping.

FIGURE No. 3-1

PRIMARY TREATMENT PLANT

Shown here with a grit channel, rectangular sedimentation tank, single stage anaerobic digester employing gas mixing, and a sludge drying bed.



CHARACTERISTICS OF PRIMARY TREATMENT PLANTS

- Sedimentation is the only means of treatment.
- (usually) the sludge is digested prior to disposal.

PRIMARY TREATMENT OF SEWAGE

PUMPING STATIONS

Sewage coming from the sewers enters the treatment facility by *gravity flow*, by *pumping stations*, or *ejector stations* located on the sewage collection system or at the plant site.

Sewage is usually screened at pumping stations to protect the mechanical equipment in the station.

Flow entering a pumping station is recorded. It enables the operator to assess the flow entering the plant, to vertify plant flow recording devices, or to detect infiltration in the collector system. Pumping stations located at critical points on the sewage collection system may be equipped with standby emergency pumping equipment to ensure that service is maintained at all times, even during major power interruptions.

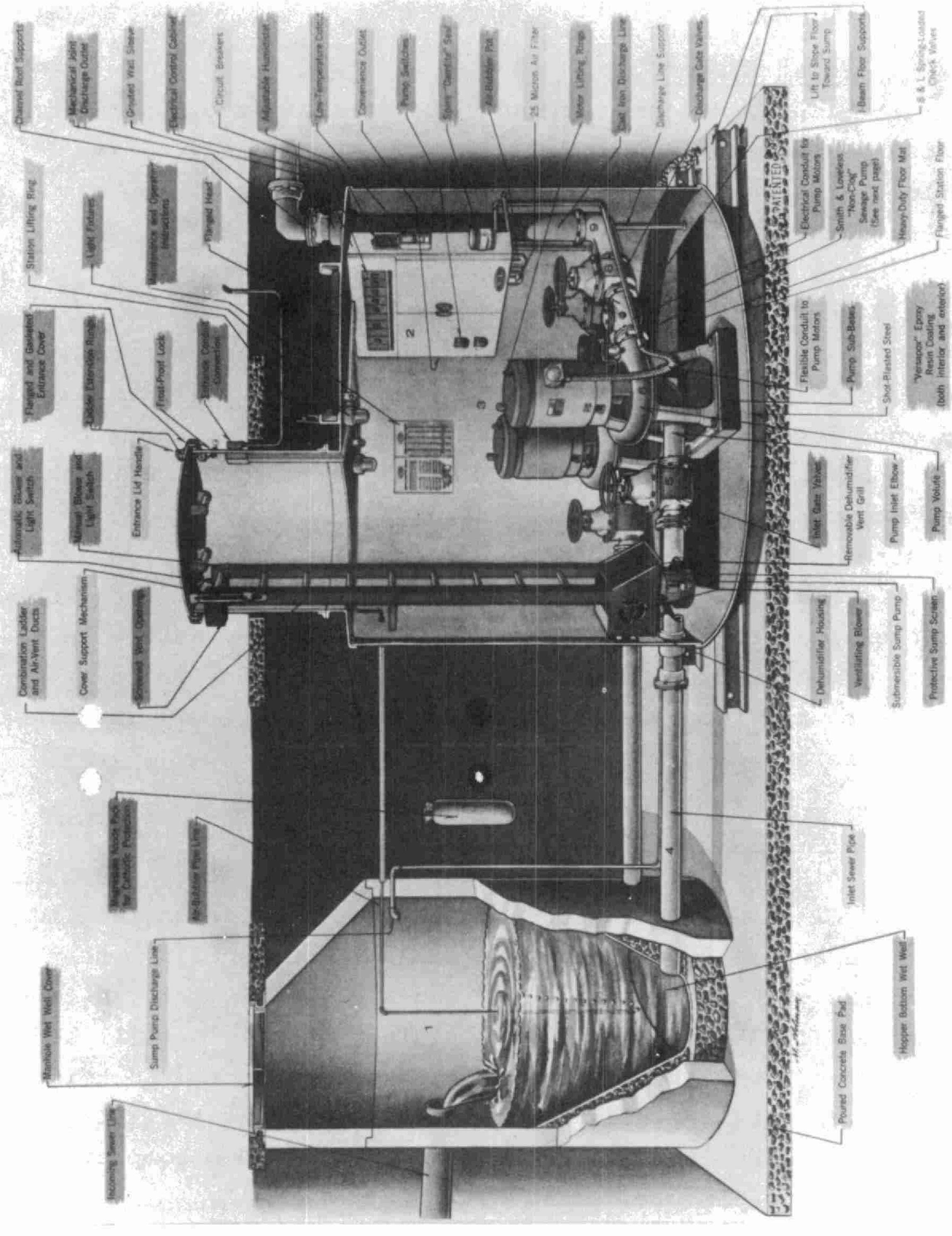
FLOW CONTROL

Flow through a pumping station is controlled by one of the following devices:

1. Manual Operation
2. Float System
3. Bubbler System (Pneumatic)
4. Electric System
5. Flowmatcher

1. Manual Operation

It is usually not economical to have an attendant at the station at all times; however, all stations should have manual control. It allows the attendant some flexibility when visiting the station. By having manual control, the attendant can test the operation of the equipment, and, in case of emergencies, can actually control the operation.



Sewage Pumping Station

Figure 3-2 (Courtesy of Smith & Loveless)

2. Float System

Simple, moderate in cost but somewhat troublesome in most raw sewage applications. The rise and fall of the float actuates mercury-tip switches that start, stop or change the speed of the pumping units.

3. Bubbler System (Pneumatic)

A small air supply causes bubbles to escape from an open-ended pipe submerged in the wet well below the lowest level to be controlled. The pressure of the air in the pipe manifold changes with the submergent depth and actuates pressure sensitive switches that start, stop or control the speed of the pumping units.

This system offers distinct advantages over the float system for use in raw sewage because the air pressure in the pipe prevents clogging, and there are no moving parts in contact with the sewage. The system is relatively inexpensive, reliable and easily serviced.

4. Electric

This system, usually of the probe type, consists of a pair of insulated electrodes positioned to contact the liquid surface at pre-determined levels. When contact is made the electric circuit is completed, and a signal is relayed to the pumps. If the liquid level is rising, the signal will activate the pumps until the level has dropped to the desired height. At this point, the electric circuit is broken, and the pumps stop until the liquid level once again rises to complete the electric circuit.

An electric system is relatively expensive and generally has a tendency to foul in raw sewage applications and requires a more frequent maintenance schedule than other systems previously described.

5. Flowmatchers

To fully understand the Flowmatcher system, a knowledge of the wound rotor induction motor is required. Basically, the Flowmatcher controls the operation of the wound rotor induction motor.

A Flowmatcher increases or decreases the resistance applied to the rotor of such a motor by altering the level of the electrolyte surrounding the resistance plates within the Flowmatcher unit.

The unit can be used in a continuous pumping operation or a start-stop operation.

The start-stop operation is preferred, since at low speeds (50% of normal full speed) wound rotor motors running for long periods exhibit a very poor power factor, will heat up and could cause *spark grooving* on the surface of the slip rings and brushes.

The units are normally used in critical operations and are subject to vigorous preventative and breakdown maintenance programs.

It is recommended that systems using Flowmatchers maintain spare components at all times. A list of suggested parts is available from the Ministry of the Environment, Project Operations Branch.

Pneumatic Ejectors

Sewage is directed to a tank causing the air in the tank to escape and be replaced by the sewage. The air exhaust is then closed and a compressed air inlet is opened which forces the sewage out the discharge pipe. The inlet pipe and the discharge pipe are each equipped with check valves to prevent back flow when filling and emptying.

Compressors are selected, based on the total head and rate of discharge required.

Advantages of this type of system are:

1. Relatively few moving parts in contact with sewage.
2. They are relatively clog free.
3. Sewage is completely enclosed.
4. The operation of this unit usually requires relatively simple maintenance procedures.

PRELIMINARY TREATMENT

Preliminary treatment devices are designed to remove or reduce in size large solids, grease, scum and grit before any further treatment of sewage. The removal of these materials protects pumps and other treatment devices from possible damage. If the preliminary treatment devices do not function as intended, maintenance costs for pump repairs, digester and clarifier clean-outs, etc., will be increased. The following units are usually associated with preliminary treatment:

1. Screens (coarse, bar, fine)
2. Comminutors (comminutors, barminutors, rotogrators)
3. Grit Removal Units (channel, aerated tanks, centrifugal separators)
4. Re-aeration

1. Screens

Screens are used to remove materials which may damage equipment, interfere with the process or which are aesthetically undesirable in the effluent. Two basic types available are coarse screens and fine screens.

a) *Coarse Screens* (commonly called *trash racks* or *bar screens*)

Coarse screens generally have bars spaced from 3/4 to 6 inches. The screens are usually installed at an angle to facilitate manual cleaning but some units are available that can be mechanically cleaned.

b) *Fine Screens*

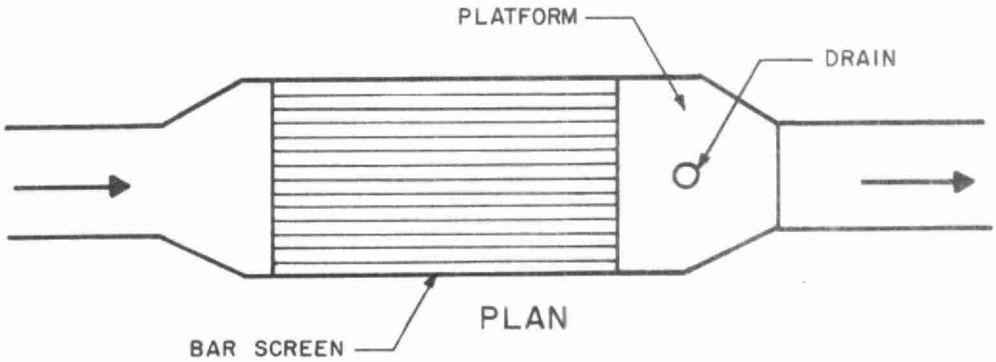
Fine screens were originally used in place of sedimentation tanks. Presently they are not commonly used in sewage treatment because the mesh will accumulate material and plug very quickly, causing what is called a *headloss* in the system. There are other operating and economical problems as well.

Figure 3-3

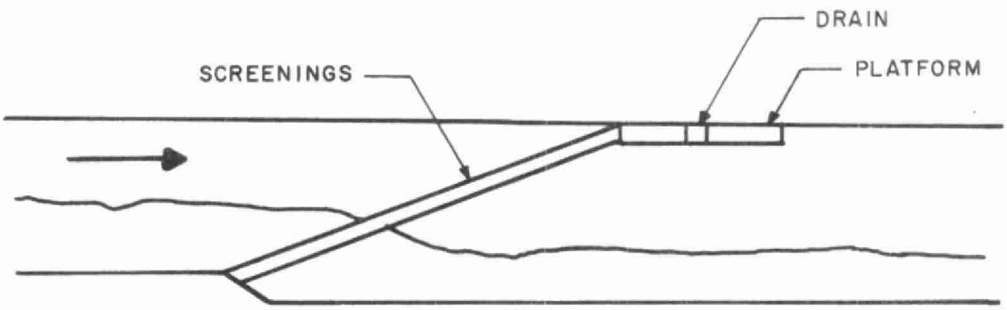
PRIMARY TREATMENT

BAR SCREEN

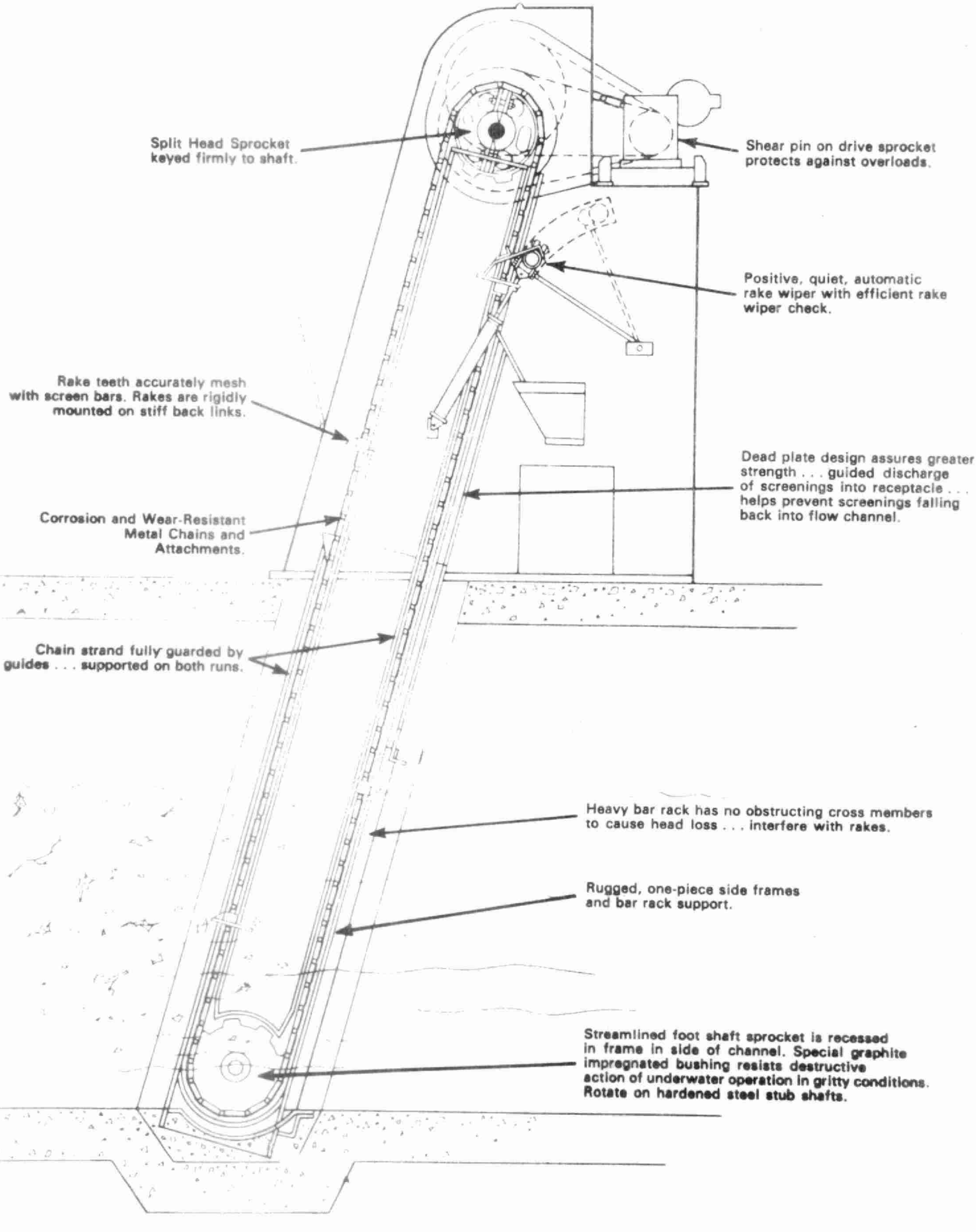
HAND RAKED



PLAN



ELEVATION



Profile View of a Mechanical Bar Screen

Figure 3-4 (courtesy of REX)

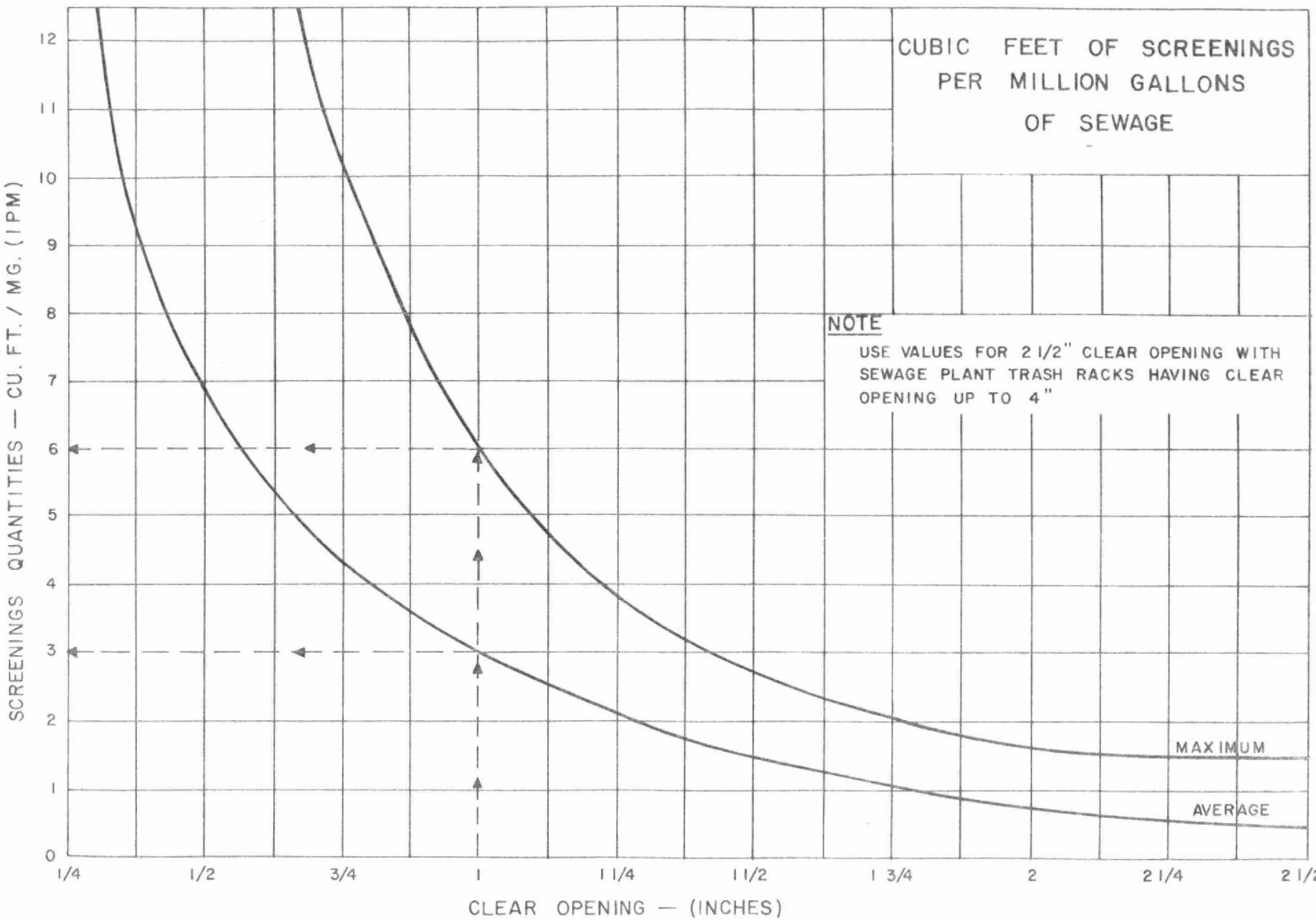

CUBIC FEET OF SCREENINGS PER MILLION GALLONS OF SEWAGE
NOTE
USE VALUES FOR 2 1/2" CLEAR OPENING WITH SEWAGE PLANT TRASH RACKS HAVING CLEAR OPENING UP TO 4"
MAXIMUM
AVERAGE
SCREENINGS QUANTITIES — CU. FT. / MG. (IPM)
0
1
2
3
4
5
6
7
8
9
10
11
12
1/4
1/2
3/4
1
1 1/4
1 1/2
1 3/4
2
2 1/4
2 1/2
CLEAR OPENING — (INCHES)

FIGURE 3-5

c) *Mechanically Cleaned Screens*

Vertical or inclined bar screens are cleaned by a mechanical *rake*. The accumulated material on the screen is pulled up the screen and "wiped" off into a hopper. Screenings are regularly removed from the hopper to prevent nuisance odours and ensure adequate capacity for incoming screenings.

d) *Cleaning Screens*

During dry weather periods, *coarse trash racks* should be cleaned daily; during storm periods, they should be cleaned two to five times per day to maintain a free flow of sewage through the process.

Failure to clean the screens can result in one or more of the following:

(i) Septic action upstream of the sewer.

(ii) Surcharge of the sewers.

(iii) Shock load on sewage units when the screens are finally cleaned.

Coarse screens, when mechanically cleaned, offer the following advantages:

(i) reduced labour costs,

(ii) better flow conditions in the process,

(iii) produce less nuisance.

The volume of material or *screenings* removed is difficult to estimate accurately. Generally, screens with openings of 1¼ to 2½ inches will collect between 1 and 12 cubic feet of screenings per million gallons of sewage. Chart 2-1 shows the maximum and average quantities of screenings that can be removed.

e) *Disposal of Screenings*

The screenings may be disposed of by burial, incineration, grinding or digestion. Burying and incinerating are the usual methods of disposal because they are the most economical methods. Most municipalities use one of these methods for disposal. *Contact your local Public Health Unit and observe local by-laws before burying or incinerating screenings.*

Remove screeings in covered containers. When burying screening odour may be prevented by sprinkling powdered lime or other odour control chemicals on the material. An earth cover of one to two feet will usually give the best results for bacterial activity. Grinding devices have been used in the past; the ground screenings are redirected to the influent flow for treatment in the process. This method has proved unsatisfactory however, as it may create digester problems. Screenings received from grinders have caused digester foaming and excessive scum blankets.

2. Comminution os Sewage

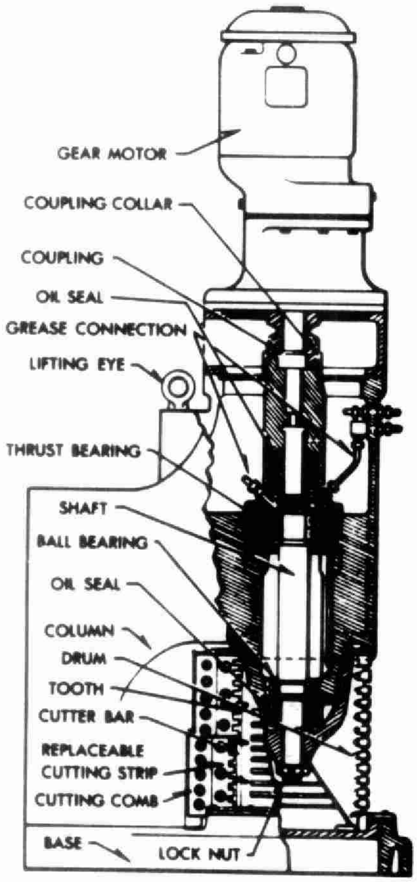
Comminutors, Barminutors, or *Rotogratores* are trade names used by different manufacturers to identify their Shredding devices. This piece of equipment is used to shred and grind large material small enough to pass through the screens of the grinding unit. Shredders should be installed with a by-pass equipped with a bar screen to facilitate removal of settled material and allow inspection of the equipment components such as the cutting edges.

Comminuting devices are normally operated continuously and are usually located ahead of the grit removal units.

3. Grit Removal Units

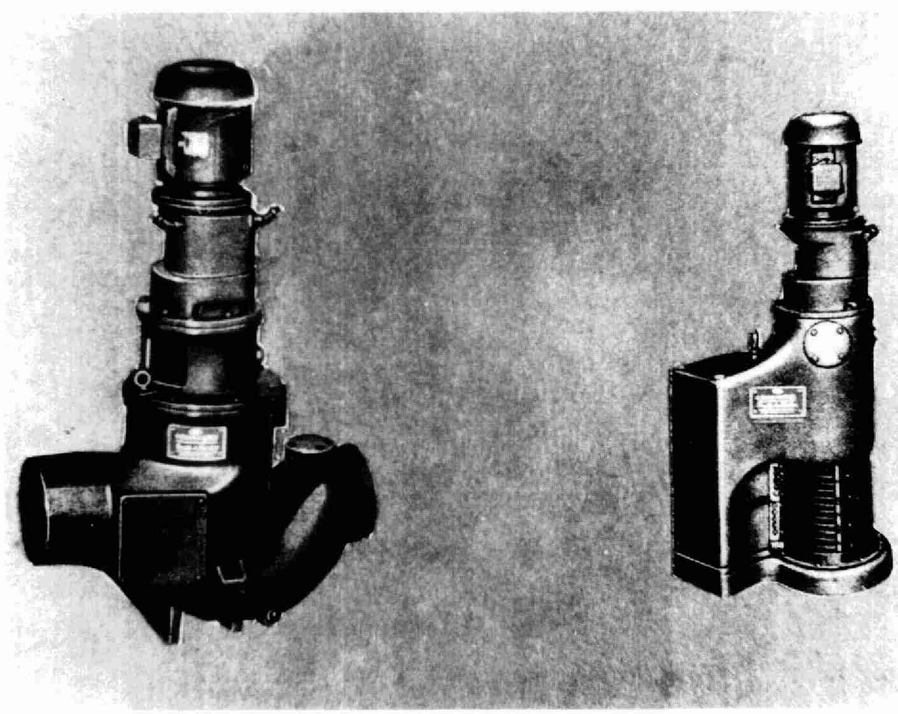
Grit such as sand, stones and gravel may find its way into a sewer system and be carried by the sewage to the treatment plant.

Grit removal units are installed after screening equipment in the process to protect mechanical equipment from abrasion, avoid pipe clogging, and reduce the sedimentation load on the primary clarifier. Grit removal devices include
(a) grit channels, (b) aerated grit chambers
(c) mechanical units.



COMMINUTOR

Figure 3-6



Inline Comminutor   Open Channel Comminutor

Figure 3-7   (Courtesy of Smith & Loveless)

(a) *Grit Channels* (see Figure 3-1)

Grit particles will settle faster than organic putrescible solids because they are heavier. Grit channels are usually designed to maintain a velocity of 1 foot per second at design flow which is usually sufficient to keep the organic matter in suspension while allowing the heavier particles to settle. Grit channels are usually rectangular and velocity control is achieved by installing a weir at the effluent end of the channel. Another velocity control device, though seldom used, is a Parshall flume.

A variation of the channel type of grit chamber is the square tank. Mechanical grit collectors are commonly used with the square tank and are similar in function to clarifier sludge collection equipment.

(b) *Aerated Grit Chamber*

Grit chambers using air to separate the lighter materials from the heavier ones are called *aerated grit chambers* Sewage flows into the aerated grit chamber and the heavier particles settle to the bottom as the sewage rolls in spiral motion from entrance to exit. The lighter organic particles eventually "roll" out of the tank. The grit at the bottom of the tank is directed to a grit hopper where it is removed by a clam shell bucket or air lift units.

(c) *Detritus Tank*

Short-period sedimentation in a tank that operates at substantially constant levels produces a mixture of grit and organic solids called *detritus*. The lighter organic solids are subsequently removed from or washed out of the mixture.

Several manufacturers specializing in sewage disposal equipment have perfected this type of equipment, For example, One such unit not only removes the grit but also washes it.

Figure 3-8

GRIT CHAMBER

HAND CLEANED, GRAVITY TYPE

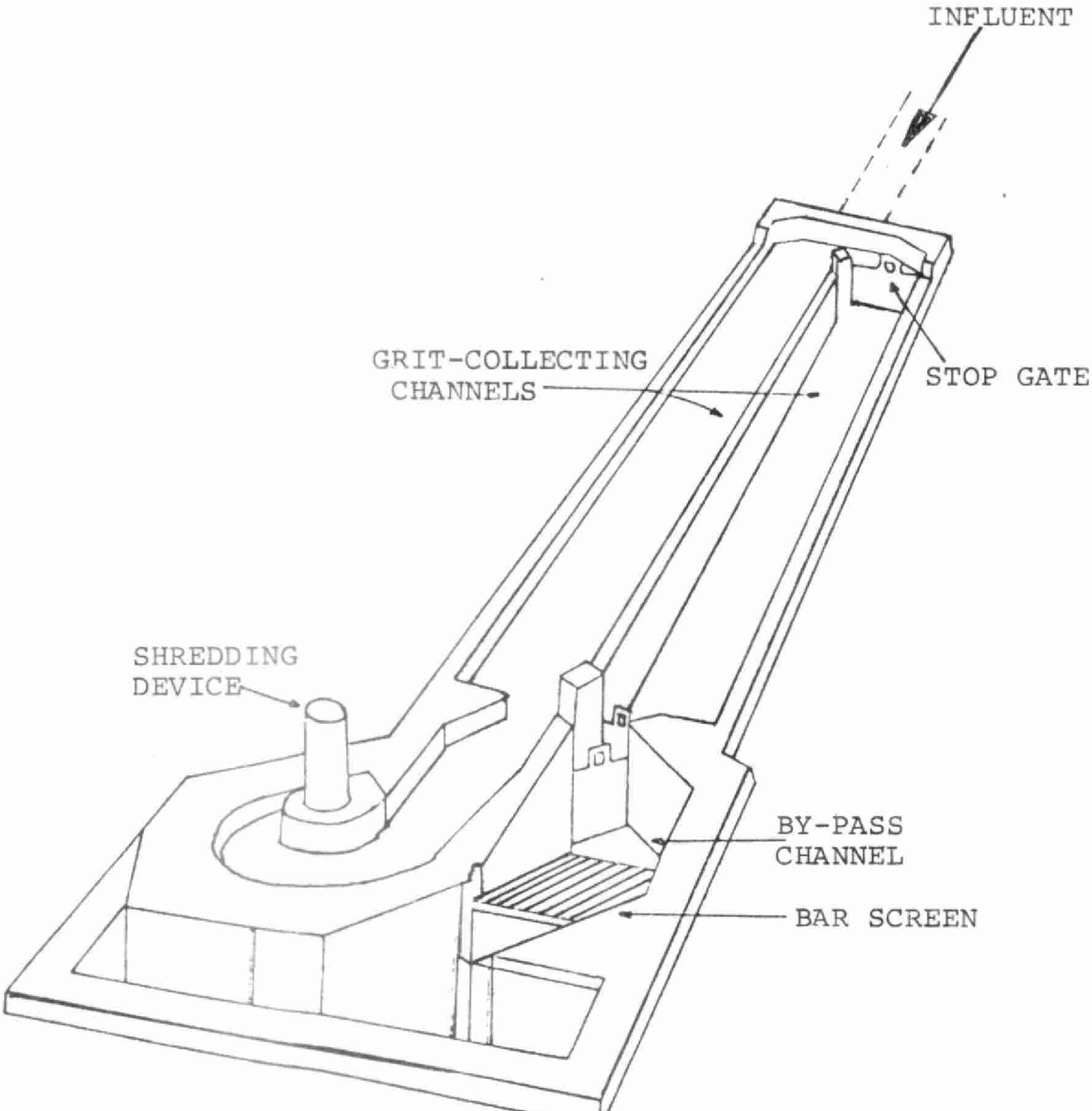
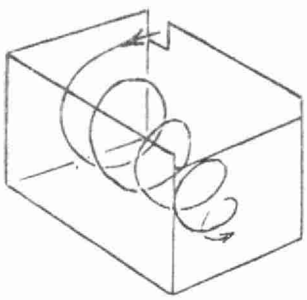
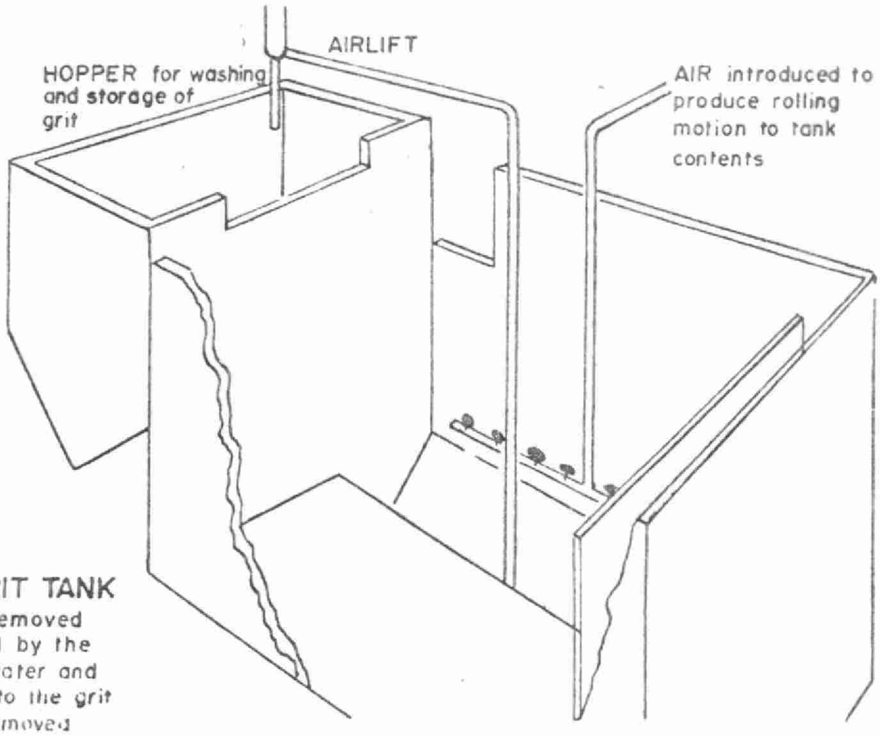


Figure 3-9



PATH OF PARTICLE SETTLING IN AN AERATED GRIT TANK



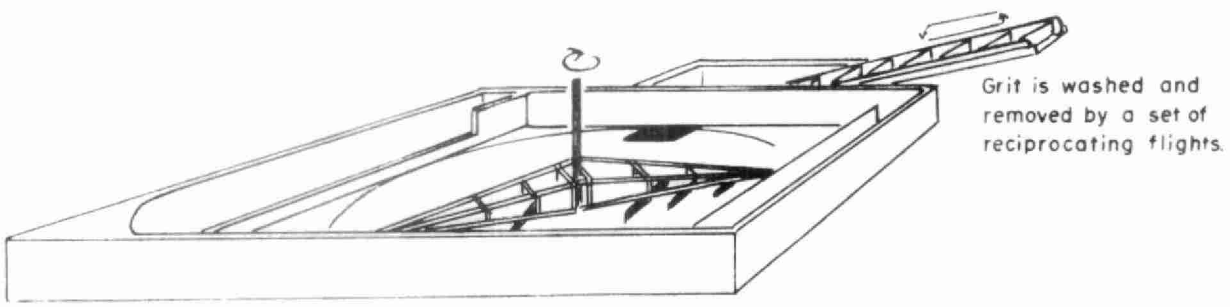
AERATED GRIT TANK

Settled grit is removed from the tank by airlift and washed by the water pumped with the grit. The water and organic matter overflow the hopper into the grit tank. Alternatively, the grit can be removed from the tank by a clam-shell bucket.

The grit-collecting mechanism is installed in a square, shallow, concrete tank with filled-in sloping corners. Sewage enters along one side of the tank through adjustable vertical gates, which are set to provide a uniform influent velocity across the entire width of the unit. Then the sewage flows in straight lines across the tank and overflows at a weir constructed along the outlet side of the tank.

The collecting mechanism consists of two structural-steel arms, attached to a vertical shaft and fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is plowed outward to the radius where the end scoops collect and discharge it to a hopper at one side of the tank.

Figure 3-10

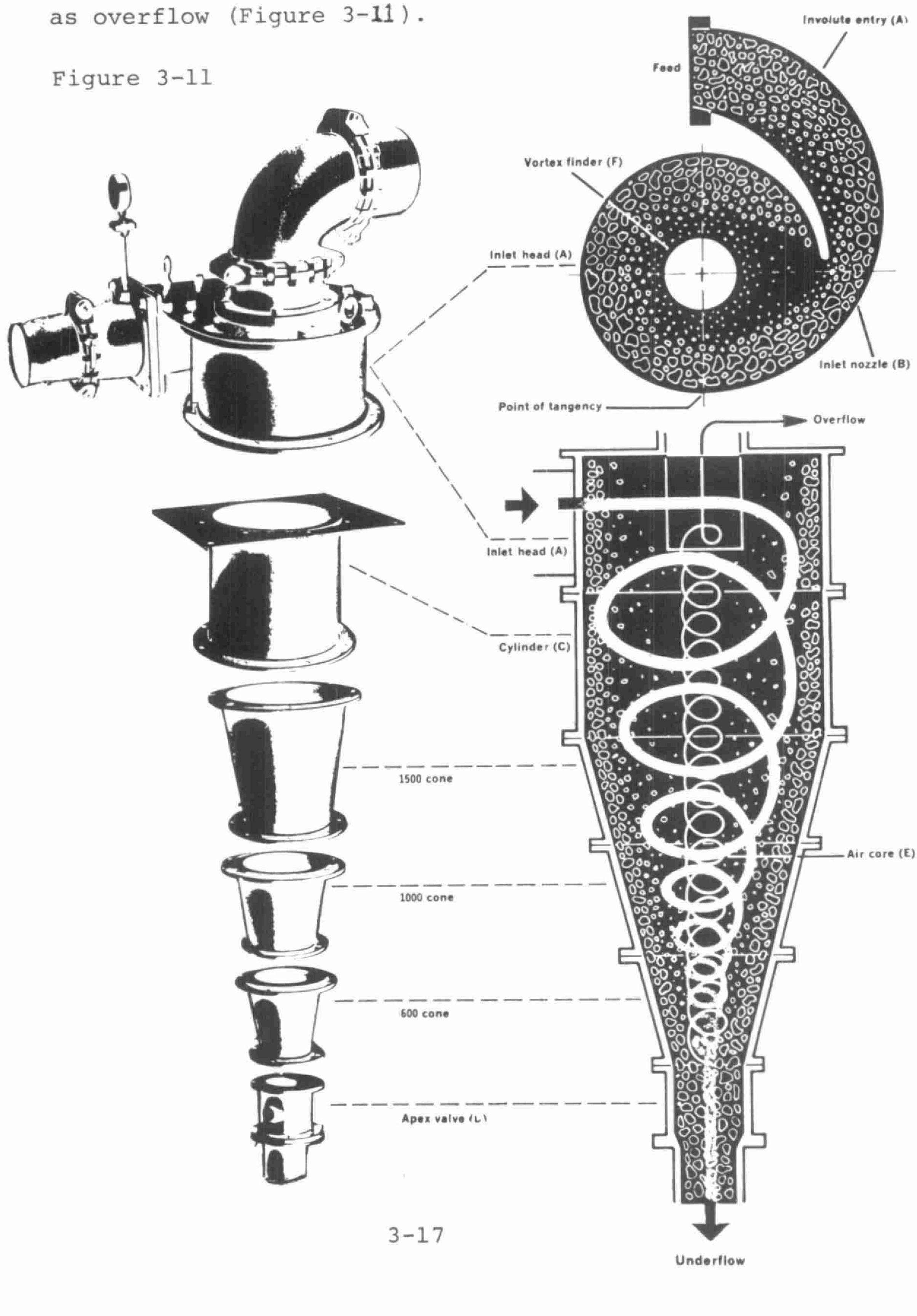


DETRITOR The grit is settled out in a shallow end-fed tank. The grit is collected and deposited by the collector mechanism. The flights move the grit and some water up the sloped trough. Water draining from the grit washes it.

(d) Centrifugal Separators

Grit removal is possible by mechanical means such as a centrifugal unit. Centrifugal units are usually liquid cyclones: the waste water is introduced tangentially into a cylindrical conical housing. The heavier larger particles of grit are thrown to the outside wall and collected for disposal. The waste water leaves the centre of the housing as overflow (Figure 3-11).

Figure 3-11



QUANTITY OF GRIT

Average figures indicate that from 3 to 8 cubic feet of grit can be collected per million gallons of sewage. The grit must be removed before it is carried by the stream flow into the primary clarifier, digester, or chlorine contact chamber.

HOW TO DETERMINE THE QUANTITY OF GRIT

Suppose 5 cubic feet of grit are presently being removed once per week. A check can be made to see if this is sufficient by doing the following: remove the grit twice per week on a trial basis. If this results in 5 cubic feet of grit each time, then removing the grit once per week is not sufficient.

It is a good practice to make periodic checks like this to ensure that the grit is not being carried to the clarifier, or digester, or chlorine contact chamber, where it would still have to be removed but with much more difficulty and expense.

The grit removal facility can reduce unnecessary maintenance costs more than any other unit. If these facilities are malfunctioning because of problems or improper operation, the result will be plugged lines, abraded impellers, and grit filled treatment tanks.

DISPOSAL OF GRIT

The disposal of grit is usually done by burial, or dumping at the municipal dump or on a landfill site. If the disposal is carried out at the plant, unwashed grit from the removal facilities should be stored in covered containers

and removed to the disposal site daily. If the grit is adequately washed (having less than 3% volatile solids remaining as determined by lab tests) it may be used as fill around the plant or may be used to re-sand sludge drying beds.

4. PRE-AERATION

Raw sewage is aerated for one or more of the following purposes:

(a) *To remove gases from the sewage*, especially hydrogen sulphide, which create odour problems and increase the chlorine demand of sewage. The release of gases and the addition of oxygen reduce odours in septic sewage. For effective results an aeration period of 30 minutes to several hours may be required.

(b) *To promote flotation of excessive grease*, which then can be removed from the raw sewage at an early stage in its treatment.

(c) *To aid in the coagulation of the colloids* (finely divided suspended solids) in the raw sewage for the purpose of obtaining a higher removal of suspended solids by primary settling.

(d) *Treatment of digester supernatant.*
Aeration basins may precede or follow screens and grit chambers. In general, pre-aeration tanks are designed for detentions of 5 to 15 minutes for grease removal, using 0.01 to 0.1 cubic foot of air per gallon of sewage treated. If flocculation of the fine suspended solids in the raw sewage is also attempted, the detention period must usually be extended to at least 15 to 60 minutes, the average time being about 30 minutes. Aeration increases the amount of skimmings or grease because the rising air bubbles attach themselves to heavier-than-water particles causing

buoyancy. This buoyancy holds the grease particles in the surface flow. Some de-emulsifying of the grease also occurs which separates it from the sewage. The skimmings are removed several times a day by hand or by skimming devices, or they may be discharged to the primary settling tanks for removal.

PRIMARY TREATMENT

Primary treatment devices remove the settleable solids and reduce the suspended solids content of the sewage by 40 to 60%. In so doing, the BOD of the sewage is also reduced by 30 to 40%.

The following units may be considered when discussing the primary treatment process:

Principal Units

1. Sedimentation tanks (clarifiers)
2. Waste stabilization ponds

Secondary and Associated Units

1. Digesters,
2. Vacuum filters,
3. Chlorine contact chambers,
4. Sludge drying beds

The primary clarifier removes, to varying degrees, the remaining settleable solids in the raw sludge. *It is the most important single facility in primary treatment.* Clarifiers are sized on a basis of settling rates and required detention time. The principle of operation is to slow down the sewage as it moves through the tank, allowing the settleable and suspended solids enough time to settle out. In so doing, the Biochemical Oxygen Demand (BOD) is also reduced by approximately 30 to 40%. Floating solids and scum are also removed in these tanks. Sludge solids are directed to digesters or vacuum filters for further treatment. Figure 3-15 indicates the amount of sludge to be removed from settling tanks. Effluent water is chlorinated before it is released to the receiving stream.

Figure 3-12

MECHANICAL SLUDGE COLLECTION
RECTANGULAR TANK

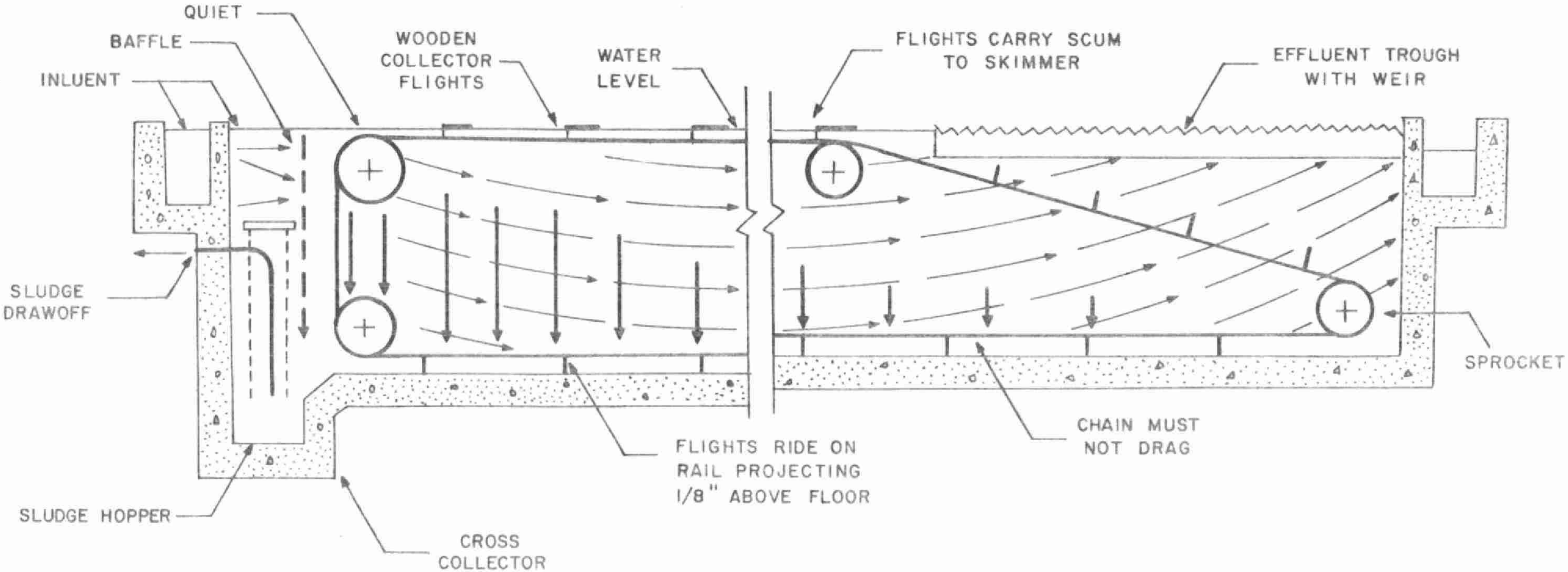
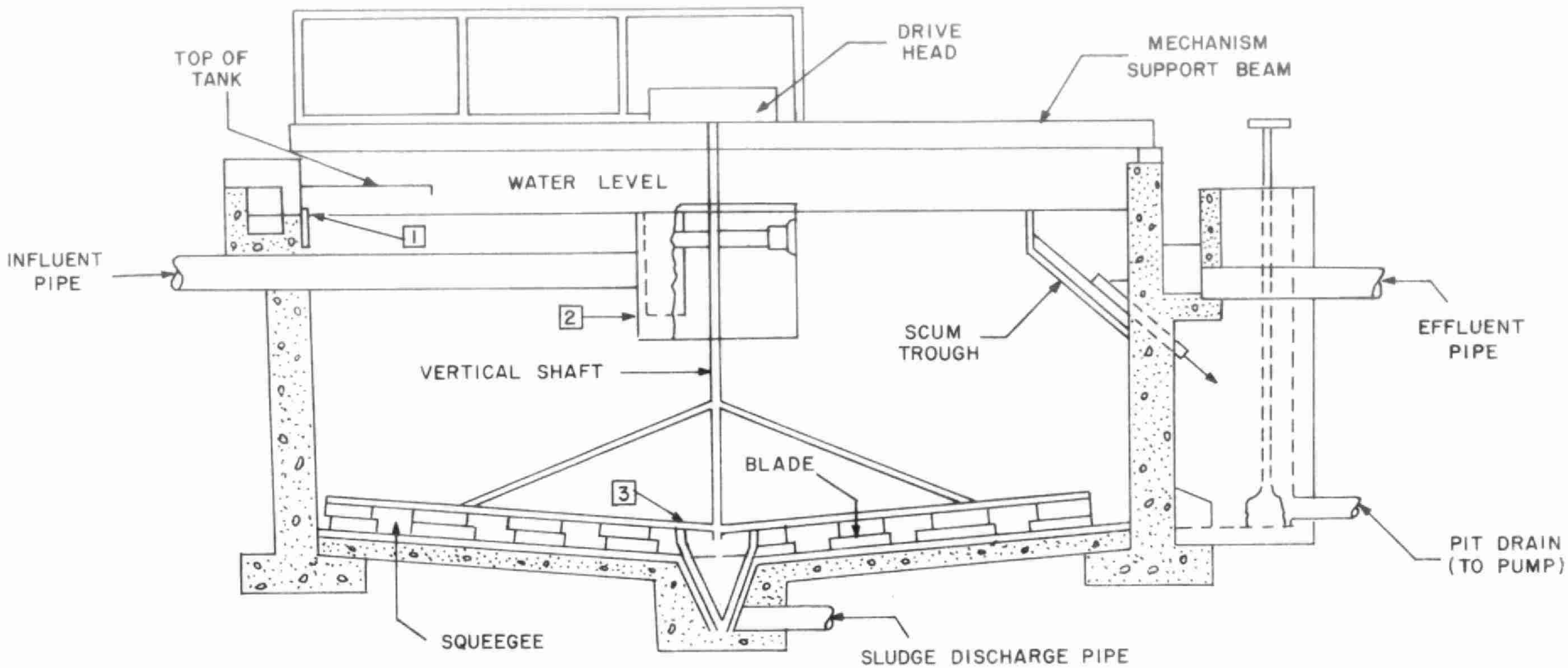


Figure 3-13

CIRCULAR SETTLING TANK
ONE TYPE



1 SAW TOOTH WEIR
2 EFFLUENT WELL
3 RAKE ARM

OPERATION OF MECHANICALLY-CLEANED SEDIMENTATION TANKS

Clarifiers or sedimentation tanks assume a variety of shapes: rectangular, square, round, and even octagonal.

In *rectangular* tanks, the sewage enters at one end and the effluent overflows the weirs near the opposite end.

Collectors operating in rectangular tanks consist of two endless chains operating on sprocket wheels and supporting wood crossbars, or "flights." The flights push the sludge to a hopper at the end as they move slowly along the bottom. For primary sedimentation the flights should move back at the surface to push the scum toward a trough at the opposite end. The trough extends across the tank and terminates in a pipe which passes through the tank wall A valve in the pipe is opened before scum is withdrawn. The scum accumulations are pushed into the trough manually and run through the pipe to a sump for further handling. Some tanks have cross-flight skimmers to do this skimming mechanically instead of manually.

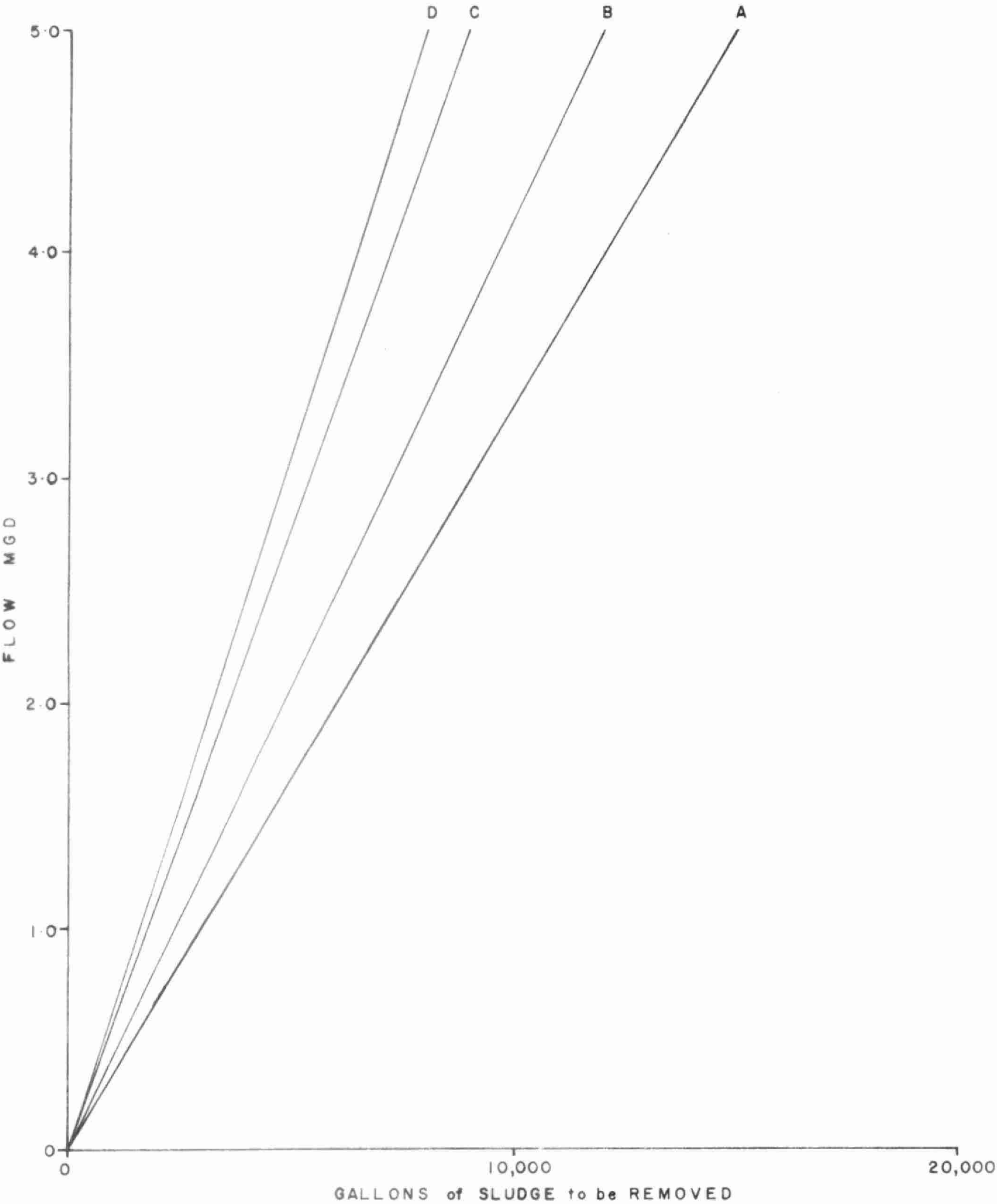
The *square* tanks can have the inlet on one side with the outlet opposite, or can be centre-fed with effluent weirs along the entire periphery. The sludge collector mechanism rotates about the centre of the tank, scraping the settled sludge into the pit in the centre and an arm on the surface moves the grease and scum to a hopper located on one side of the tank.

Circular tanks can be either centre-fed or peripherally-fed. The sludge collector mechanism is similar to that of the square tank.

In general, sludge collecting mechanisms in circular tanks are operated over longer periods than collectors in rectangular tanks. Collectors should be run often enough to prevent a build-up of solids in the tank from causing an undue load on the mechanism at start-up and damaging the equipment. Also, the tank volume is reduced, resulting in a lower retention period. Solids may decompose, producing gas in the settling tank and floating sludge. Before sludge is removed from the tank the mechanism should be run long enough to assure satisfactory collection of solids

FIGURE 3-14

PRIMARY SLUDGE REMOVAL



in the bottom of the sludge hopper.

Establish and maintain proper time schedules for operation of the mechanical cleaning equipment and for the removal of sludge from the tank. Schedules must be determined for individual plants. General maintenance should include daily cleaning of all vertical and inclined walls and the removal of all material from baffles and algal growths from weirs.

SLUDGE WITHDRAWAL

Raw sludge withdrawal should consist of a sludge as dense as possible, preferably in the range of 5 to 7 per cent total solids. The settling tank hoppers should be cleared as thoroughly as possible without drawing liquid. Sludge may be removed by hydro-static pressure in some installations or by pumping. The manner in which sludge is removed has a great effect on both the settling tank and the digester.

It is generally better to remove sludge three to four times a day and provide a more constant food supply to the organisms doing the work, than to remove all of the daily sludge accumulated at one time. If too little sludge is removed, the clarifier effluent will deteriorate. If too much is removed, the digester operation will deteriorate and extra supernatant must be treated.

A constantly watery sludge would indicate that too much sludge is being pumped; i.e., the sludge concentration in the digester is not allowed to increase. If a thick sludge is being pumped at the beginning of the pumping cycle and turns watery towards the end, the pumping rate is too high. In this case, the volume of sludge entering the pit or hopper is not as great as the amount being pumped out of it. Since the pumping rate is not easily adjustable, the length of the pumping cycle should be decreased and the pumping frequency increased. At a primary treatment plant, a general guide would be to pump approximately 3,000 gallons of sludge per million gallons of raw sewage treated; the

exact amount to be pumped will depend on local conditions. Gas bubbles and pads of black sludge on the surface are an indication that the settled sludge is becoming anaerobic. In this case, the frequency and the amount pumped should be increased to remove the sludge more quickly and thus prevent these conditions. If the sludge is particularly difficult to pump even though there is little sludge in the tank, check the volatile solids. If they are less than 50%, this probably indicates that an excessive amount of grit has found its way into the clarifier. A more frequent cleaning of the grit facilities should rectify this.

Scum Removal

Scum is formed by foreign matter that rises to the surface. It should be pumped out of the tank before pumping the sludge, if possible. By doing this, any grease remaining in the pipes will be scoured by the sludge when it is removed. Removal of scum, floating garbage and grease is essential for efficient operation of settling tanks. A scum barrier or baffle is generally provided in the flow path between the centre of the tank and effluent weir. Excessive skimming will result in too much water being carried out with the scum, while insufficient skimming will permit scum to flow around or under the baffle and escape with the tank effluent. Scum must be removed daily, and ideally, small amounts should be removed continually rather than a large batch at one time.

Chemical Precipitation

Chemical precipitation is a modified sedimentation process in which a coagulant is employed to improve the efficiency of settling. Chemicals used include alum, ferric chloride and lime. Proper mixing of these is essential and the dosage will vary according to the characteristics of the sewage being treated. Efficiencies of 80% to 90% removal of suspended solids and 50% to 55% removal of BOD are common

when using chemical precipitation. However, the use of chemicals is an expensive operation and produces a high volume of sludge which may be difficult to dispose of, further adding to operating costs.

<u>GALLONS OF SLUDGE TO BE REMOVED</u> (Figure 3-15)
(Based on Following Parameters)

1. 5% Total Solids
2. 60% Removal of Suspended Solids

Curve A: influent s.s. - 250 ppm
(effluent s.s. - 100 ppm)

Curve B: influent s.s. - 200 ppm
(effluent s.s. - 80 ppm)

Curve C: influent s.s. - 150 ppm
(effluent s.s. - 60 ppm)

Curve D: See *NOTE*

The operator should now compare his sludge pump capacity with the amount to be removed and arrive at a figure for timing his sludge removal to prevent removal difficulties noted elsewhere in this chapter.

NOTE:

For actual removals, the spacing of the curves on the graph change as follows (see curve D):

1. Assume inlet s.s. - 200 ppm
(measured in lab)

Assume outlet s.s. - 120 ppm
(measured in lab)

Therefore removal is 40% = 80 ppm

Therefore amount of sludge to be pumped at 1 MG plant flow rate and 5% solids

$$= 80 \times \frac{100}{5.0} = 1600 \text{ gallons}$$

Therefore amount to be pumped at 5 MGD = 8000 gallons

FORMULA

If influent s.s. = A ppm

and effluent s.s. = B ppm

Therefore amount removed = (A - B) ppm

Therefore gallons of sludge to be pumped at flow rate of 1 MGD through primary section and at Q% total solids

$$= (A - B) \times \frac{100}{Q} = G$$ (gallons of sludge to be removed)

(Where flow rates differ from 1 MGD multiply "G" by appropriate fraction of 1 MGD.)

WASTE STABILIZATION PONDS (LAGOONS)

Waste stabilization ponds are usually constructed where land costs are low and land availability is high. They are an economical and simple treatment system.

Lagoons are generally sized on a BOD loading of 20 pounds of BOD per acre, per day, which is approximately equivalent to 100 persons per acre per day.

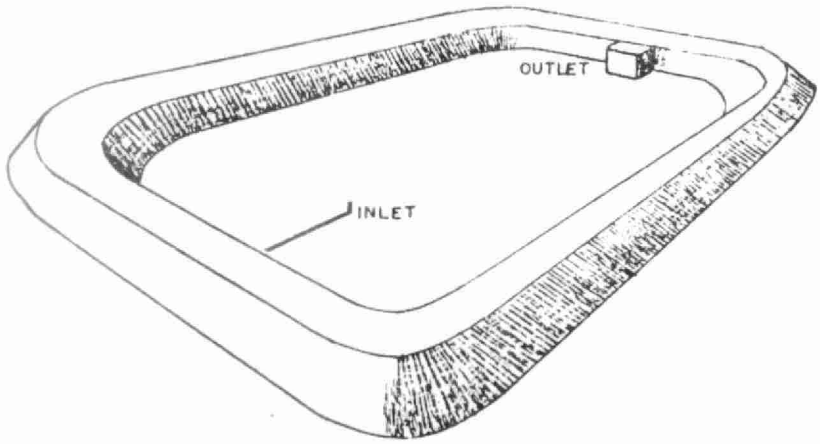
Berms are constructed with side slopes of 4:1 (25% grade to help control erosion which could give rise to "break-through" of the lagoon contents. The maximum liquid level in the cell is usually maintained at five (5) feet; beyond this level, anaerobic decomposition may occur in the low depths of the cell and result in poor treatment of the sewage. Construction of deeper lagoons would also tend to increase the initial cost.

Sewage is directed to lagoons through a distribution box, where there is more than one cell, or pumped directly into a single cell through an upturned inlet pipe. (Figure 3-16)

A natural aerobic decomposition cycle occurs (Figure 3-17) in the cell. Effluent water "overflows" the cell(s) and is directed to the receiving stream. *The Ministry of the Environment requires that effluent BOD be 15 ppm.*

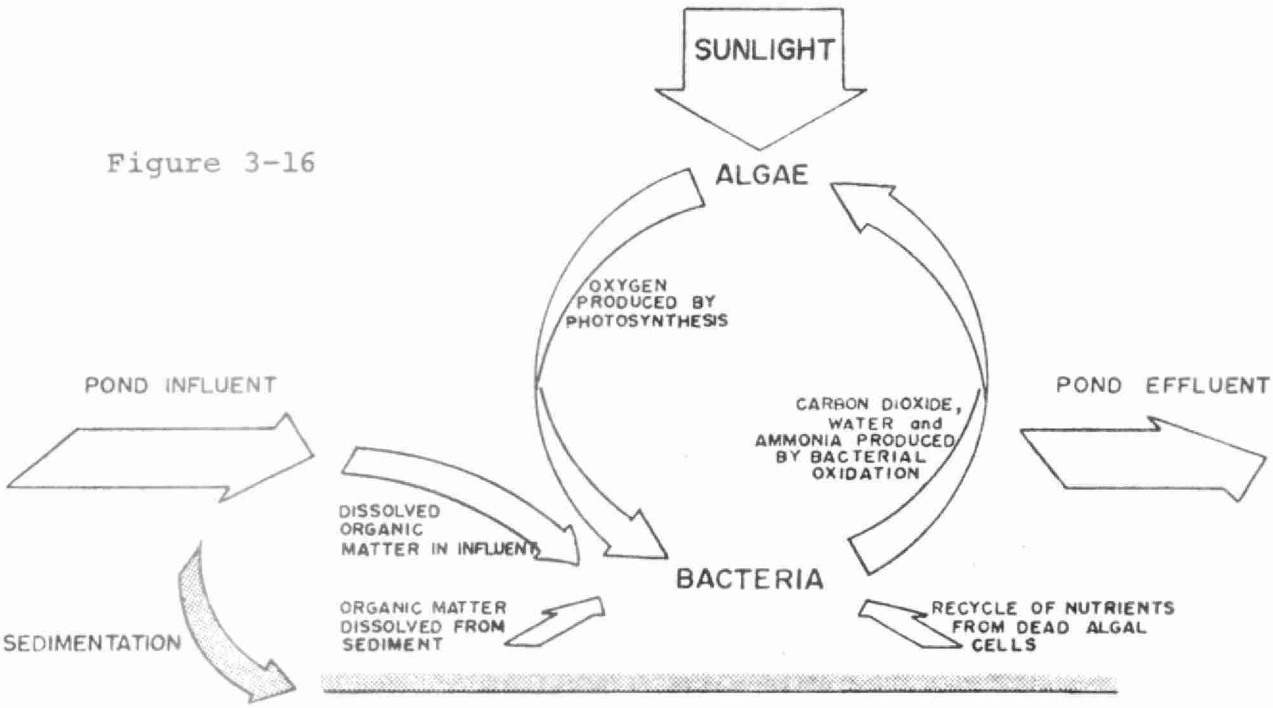
Waste stabilization systems in Ontario are almost entirely operated on a seasonal retention basis. (i.e., the cell contents are lowered in the Spring during high run-off period, and again in the Fall). Public use of receiving streams in the summer and poor treatment of sewage in winter are the main reasons that this method is used.

Figure 3-15



WASTE STABILIZATION POND The pond has a flat floor and the normal water depth is about five feet.

Figure 3-16



PROCESSES OCCURRING IN A WASTE STABILIZATION POND including the symbiotic algae - bacteria relationship.

Some of the more common operating problems are as follows:

1. Lagoon inlets and distribution chambers plugging with sand (in sewer systems susceptible to sand infiltration).

2. Vandalism causing plugged or blocked pipes or distribution chambers.

3. Mosquito breeding due to lack of grass cutting on and around the lagoon berms.

4. Frozen inlet due to excessive lowering of the liquid level in the cell in preparation for winter operation. (Liquid levels should be maintained at least 12 inches above the inlet pipe.)

5. Berm erosion due to wave action in large cells.

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 4

BASIC CONSIDERATIONS OF

ACTIVATED SLUDGE PROCESS

OBJECTIVES:

Trainee will be able to:

1. Describe in general terms the Activated Sludge Process.
2. Name the three major portions of the Activated Sludge Process.
3. Name three factors which have a major effect on the Activated Sludge Process.
4. Describe the effects on the process of having: too much food; insufficient food.
5. Describe the three main functions of the aeration tank.
6. Name two methods of dissolving oxygen into the aeration tank.

BASIC CONSIDERATIONS OF ACTIVATED SLUDGE PROCESS

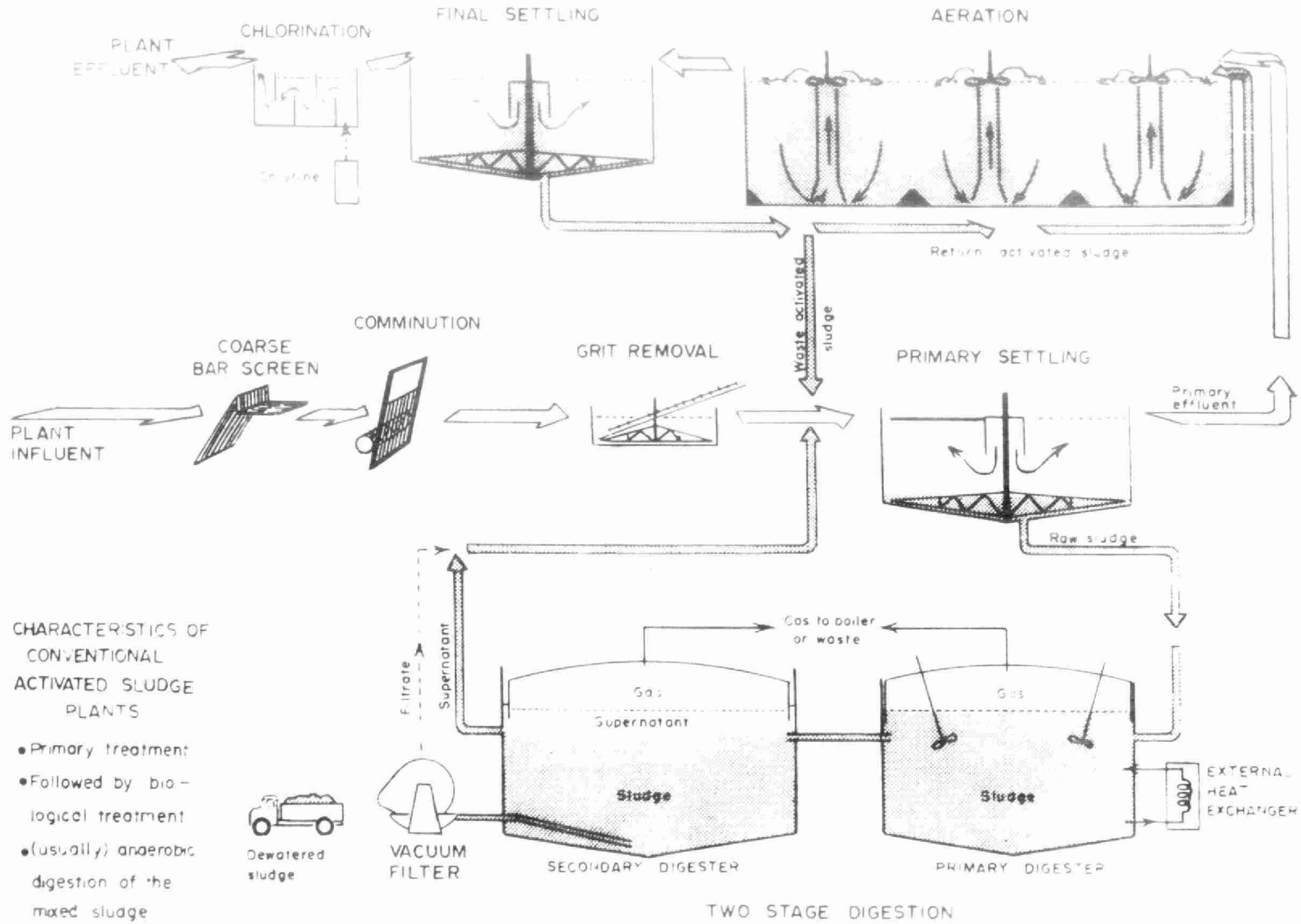
After primary treatment, usually by sedimentation and flotation, the treated sewage effluent still contains 60 to 70 per cent of its original organic contaminants. These are in the form of very fine or dissolved organic materials not readily removed by normal mechanical or physical methods. However, most of this material can be broken down biologically by naturally present bacteria. These bacteria, in the presence of oxygen, decompose organic materials. This is the principle used in the *activated sludge process*. Basically, this process consists of an aeration tank where the liquid wastes are aerated in the presence of microorganisms until all organic matter in the sewage is stabilized. These organisms are then separated from the now treated wastes and settled out in the final clarifier to be recycled and used again. The overflow from this clarifier is a fairly clear liquid which, after disinfection by chlorination, is discharged to a receiving water (stream or lake).

The conventional wastewater treatment process can be divided into four major portions (Figure 4-1):

1. Primary Treatment
   (a) Bar Screens
   (b) Communitors
   (c) Grit Removal Devices
   (d) Settling Tank

2. Secondary Treatment (Activated Sludge Process)
   (a) Aeration Tanks
   (b) Final Settling Tanks
   (c) Sludge Recirculation

FIGURE No. 4-1 CONVENTIONAL ACTIVATED SLUDGE



3. <u>Sludge Treatment and Disposal</u>
   (a) Aerobic or Anaerobic Digestion
   (b) Centrifuges
   (c) Vacuum Filtration
   (d) Sludge Drying Beds
   (e) Liquid or Solid Sludge Haulage

4. <u>Disinfection</u>
   (a) Chlorination

The purpose of this chapter is to discuss the *secondary* treatment process:

1. The principle of activated sludge process.
2. The functions of the aeration tank.
3. The final settling tank and sludge recirculation.
4. Factors affecting the activated sludge process.

THE PRINCIPLE OF ACTIVATED SLUDGE PROCESS

Following primary treatment, the primary effluent contains suspended and dissolved organic materials. If left untreated, these will cause odours and, eventually, pollution. These are the materials removed in the activated sludge process, by a reduction known as *biochemical oxidation.* Activated sludge contains many types of bacteria and other microorganisms so small that they cannot be seen without the aid of a powerful microscope (500X magnification). The bacteria are the smallest and the most important group of microorganisms in this process, since they are responsible for oxidizing the organic matter. The bacteria, in the presence of dissolved oxygen, utilize the organic matter as food to reproduce and expand the population in a normal life cycle. The other microorganisms, which are slightly larger and higher life forms, act mainly as scavengers of free swimming bacteria not associated with the sludge.

A good activated sludge should flocculate (Figure 4-2), should be brown, and normally has an earthy odour. It is a mixture of dead biological cell material, small organic solids, and living microorganisms commonly referred to as *mixed liquor* (Figures 4-3 and 4-4). It is this solids mass which provides the base to which bacteria cling. These bacteria are known as *aerobic* bacteria, requiring oxygen in order to live. In the presence of oxygen, the bacteria are able to break down the complex organic substances in sewage into simpler organic compounds, which in turn are broken down by different bacteria to nitrates, phosphates, carbon dioxide and water. The activated sludge process is, therefore, an aerobic process and as such must be supplied with oxygen at all times. Without oxygen, the bacteria will die, the oxidation process will come to a halt and a foul smelling black sludge will be left. In this state, the sludge is said to be *anaerobic* (that is, lacking oxygen). In order to dissolve oxygen into the waste, the activated sludge, the microorganisms, and the primary effluent are aerated and mixed in an aeration tank.

THE AERATION TANK

The breakdown of organic materials in the wastewater takes place in the aeration tank. This is achieved by bringing the organic materials into contact with the bacteria in the presence of dissolved oxygen long enough to permit the breakdown to occur. The aeration tanks can be square, rectangular or circular and generally are 10 to 15 feet deep. The tank size depends on the volume of sewage to be treated and its ability to hold the incoming sewage for a period of 4 to 8 hours. The tanks are generally made of concrete or steel, although in some very isolated instances wood has been used. Oxygen is dissolved into the wastewater

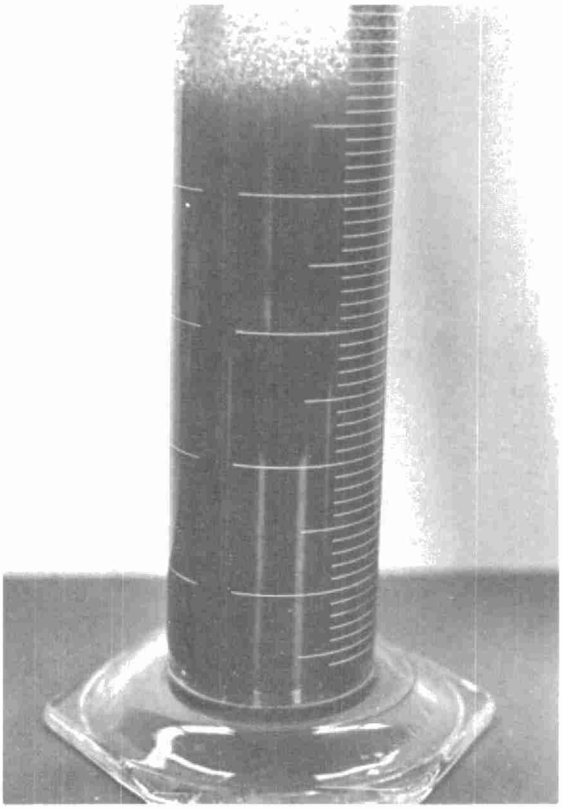


Figure 4-2

30-minute settling test

Figures 4-3 & 4-4 Protozoa Organisms
(Magnification 300X)

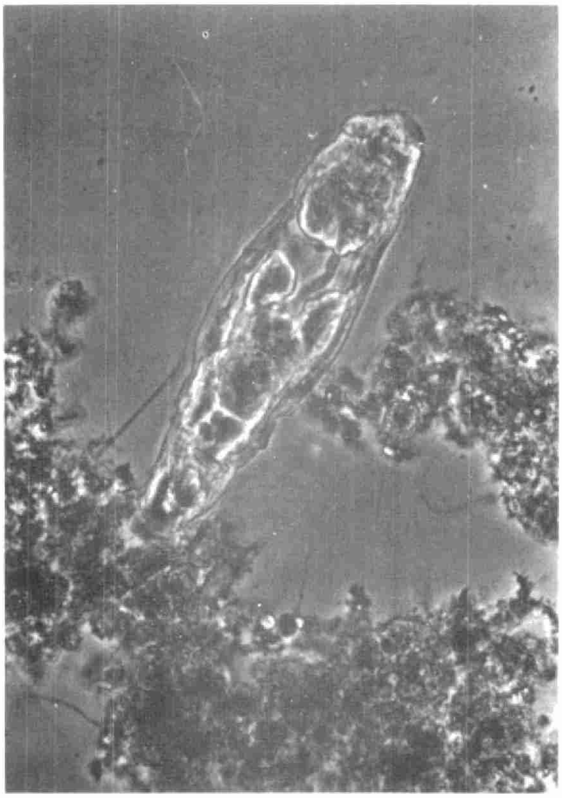


Figure 4-3 Rotifer

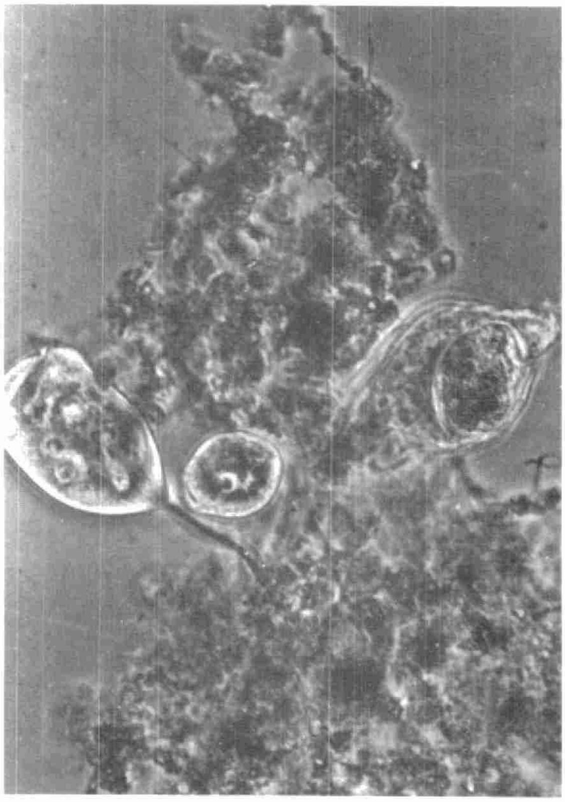


Figure 4-4 Ciliophora

in tanks, either by diffused aeration or surface aeration. *It is essential that adequate mixing is provided,* so that the activated sludge is maintained in suspension.

a) Diffused Aeration

In this type of aeration system, air is blown from the compressors through various types of devices located at the bottom of the aeration tanks, generally on one or both side walls of the tank. While oxygen is being dissolved into the liquid, a rolling action is generated to ensure thorough mixing and suspension of the activated sludge.

b) Surface Aeration (Mechanical aeration)

This technique uses blades of various designs rotating partially submerged at the surface of the liquid with dissolved oxygen from the atmosphere. These devices splash large volumes of liquid over the surface of the tank entraining and dissolving atmospheric oxygen into the tank contents. This also generates pumping action for the necessary mixing. The amount of oxygen which can be dissolved varies with the speed of the device, its diameter, submergence, and the horsepower of the drive unit. The drive motor ranges from 5 to 150 horsepower and the device can be as big as 10 feet across.

THE FINAL SETTLING TANK

The secondary clarifier, or final settling tank, receives the activated sludge from the aeration tank. This unit is essential to the activated sludge process since it is here that the microorganisms are separated from the now purified wastewater. The microorganisms in the form of sludge (called activated sludge) settle to the bottom of this clarifier where, with the aid of scraper mechanisms, they are

collected and returned to the aeration tank to treat more wastewater. The treated wastewater, with only 10 percent of its original contaminants remaining, flows over weirs to be disinfected before discharge to the receiving rivers or lakes.

FACTORS AFFECTING THE ACTIVATED SLUDGE PROCESS

Since the bacteria do the work in the activated sludge system, the factors affecting the system are those affecting the bacteria. As with all life forms, these organisms can only live if conditions remain suitable for their growth. The following are the main considerations in maintaining activated sludge:

1. Since the bacteria are aerobic, oxygen must be present for the organic materials to be broken down. For satisfactory operation of the activated sludge process, a dissolved oxygen concentration in the aeration tank of at least 1 mg/l should be present at all times.

2. As with all other life forms, a second requirement is food. In this case, the organics in the sewage provide the food supply for the bacteria. The bacteria themselves are the food for some of the higher life forms. Insufficient food will result in cannibalism amongst the bacteria, while an excess causes a shortage of dissolved oxygen and the growth of filamentous bacteria which are undesirable (Figure 4-5).

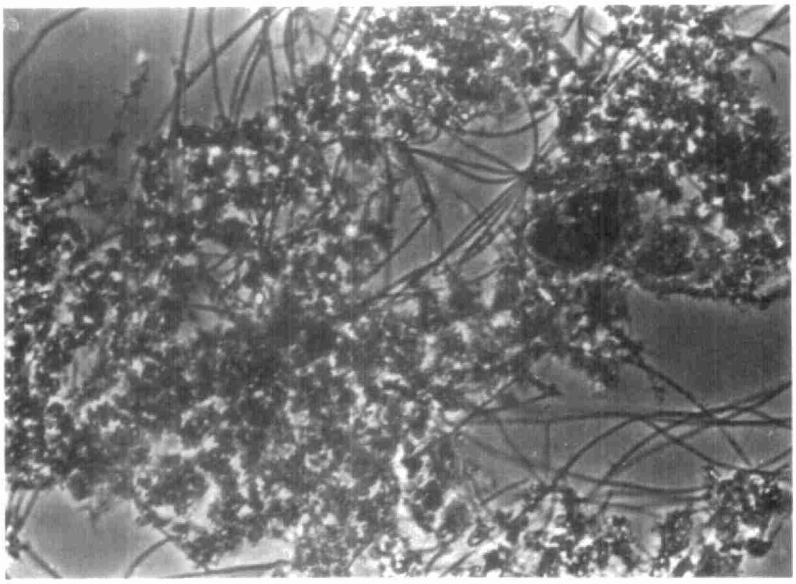


Figure 4-5

Filamentous organisms in activated sludge.

3. It is also necessary that no toxic materials should come into contact with the microorganisms. The most likely toxic conditions which occur in the wastewater treatment process are caused by industrial discharges. The commonest cause is chemicals resulting in pH conditions outside the range of pH:6 to 8.5, and soluble chemicals such as *cyanide*, *copper*, *chromium* and *nickel* which are themselves toxic to the microorganisms. It is essential, therefore, that these chemicals are eliminated before they come into contact with the microorganisms forming the activated sludge.

SUBJECT:

BASIC SEWAGE TREATMENT OPERATION

TOPIC: 5

VARIATIONS OF THE ACTIVATED SLUDGE PROCESS

OBJECTIVES:

Trainee will be able to:

1. Identify at least 4 variations of the activated sludge process.

2. Describe briefly each process and its application.

3. List at least 3 routine laboratory tests for making quick changes or spot efficiency checks in the plant operation.

VARIATIONS OF THE CONVENTIONAL ACTIVATED SLUDGE PROCESS

Variations on the conventional activated sludge process include:

a) Total oxidation

b) Extended aeration

c) A variation of conventional aeration

d) Contact stabilization or reaeration

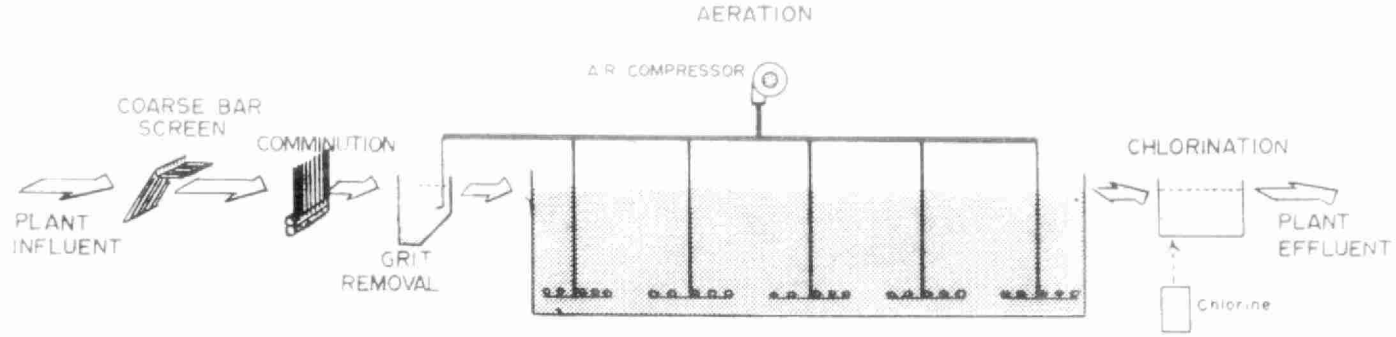
a) Total Oxidation

Basically, total oxidation is a large aerated tank (Figure 5-1) with no built-in provision for sludge removal. The effluent from this system may be sent to a lagoon for further clarification, since the effluent from the total oxidation process has a high level of what is called "pin-point floc". This form of treatment is seldom constructed as such because of the high initial capital cost for tank construction. However, it may be the actual process involved in the early stages of extended aeration. The total oxidation plants require minimum supervision and are normally reserved for small rural installations.

b) Extended Aeration

In the extended aeration process, the aeration tank is smaller than the above installation and a final clarifier is part of the system. Surplus activated sludge produced is wasted to a holding tank for subsequent removal (Figure 5-2). The average retention times in the aeration units are from 12 to 24 hours. Removal of BOD is very high, and the effluent level is frequently below

Figure 5-1 TOTAL OXIDATION

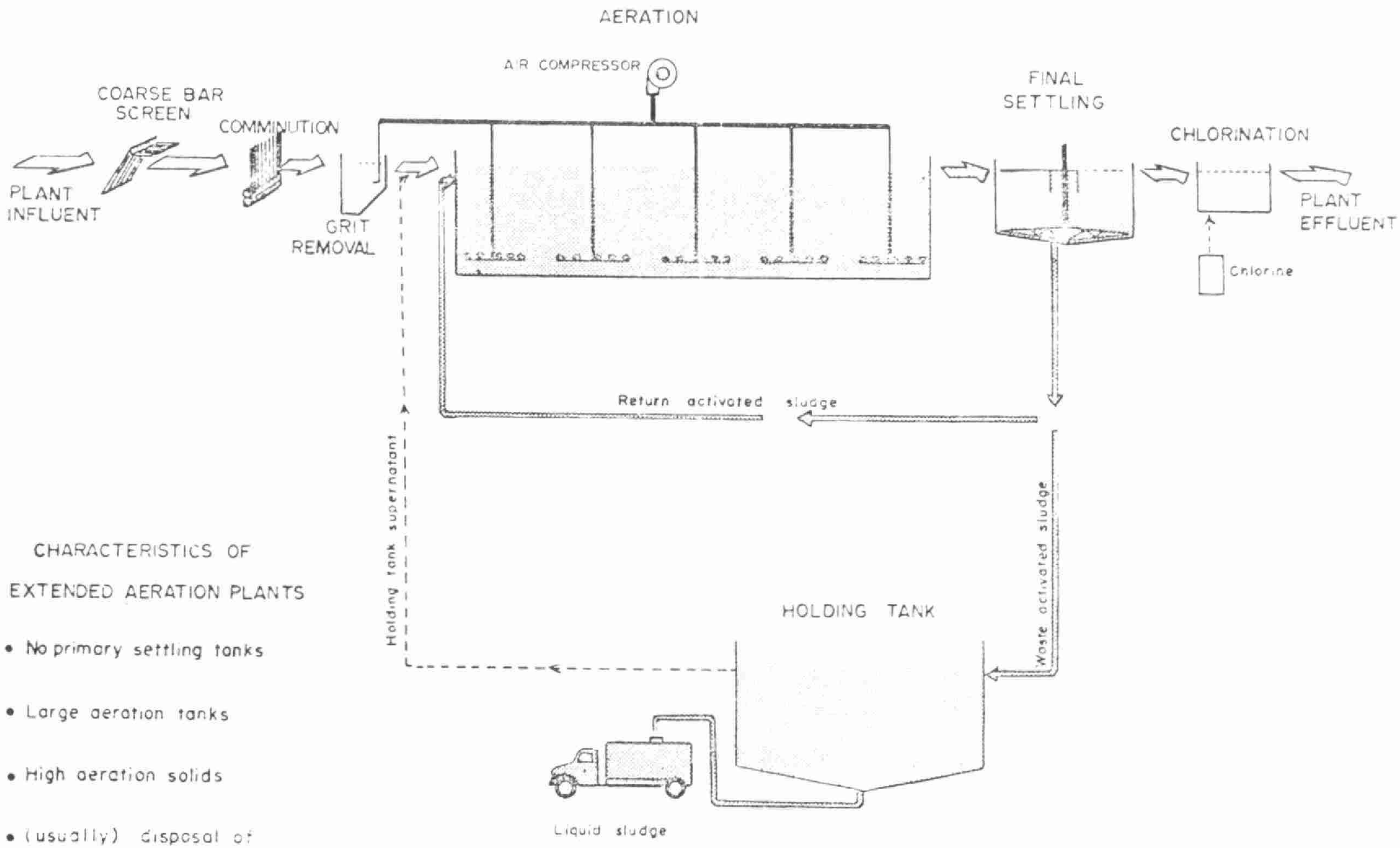


Characteristics Of Total Oxidation Plants

- No primary settling tanks
- Large aeration tanks
- High aeration solids
- No provision for sludge removal

FIGURE 5-2 EXTENDED AERATION

Shown here with an aerated grit tank, aeration by diffused air, circular centre-fed clarifier, and a decanted sludge holding tank.



CHARACTERISTICS OF EXTENDED AERATION PLANTS

- No primary settling tanks
- Large aeration tanks
- High aeration solids
- (usually) disposal of raw waste activated sludge

the 15 milligram/litre objective. However, an ash floc is produced due to the long retention time and the suspended solids content in the effluent from this type of plant is often above the 20 milligram/litre level. An extended aeration plant requires minimum supervision and may be constructed as the ultimate design for this reason, or may be used as an interim process in a conventional activated sludge plant until the loading increases to the point where it can no longer be applied.

Another form of an extended aeration process which is often used in rural, low density, or fluctuating population areas, is the *oxidation ditch* which is a race track with a surface beater (Figure 5-3). Sludge removal and return is provided, requiring minimum supervision.

The extended aeration process is also applicable in a plant designed and constructed to meet a 20-year goal and having surplus tank capacity in the early years. This is found in the package plant design where the functions of the units can be changed by manipulating certain valves, as the loading on the plant increases through the years. In cases like this, there is usually surplus air capacity available, or space has been provided for its installation when required.

c) Conventional Aeration

If we maintain these relative processes in their descending order of retention time we would now come to the conventional activated sludge process which has a retention time of between 4 to 6 hours. Surplus activated sludge has to be wasted continuously and is usually put into a digester to reduce its volatile content. The conventional process is on the list of diagrams for comparison (Figure 5-4).

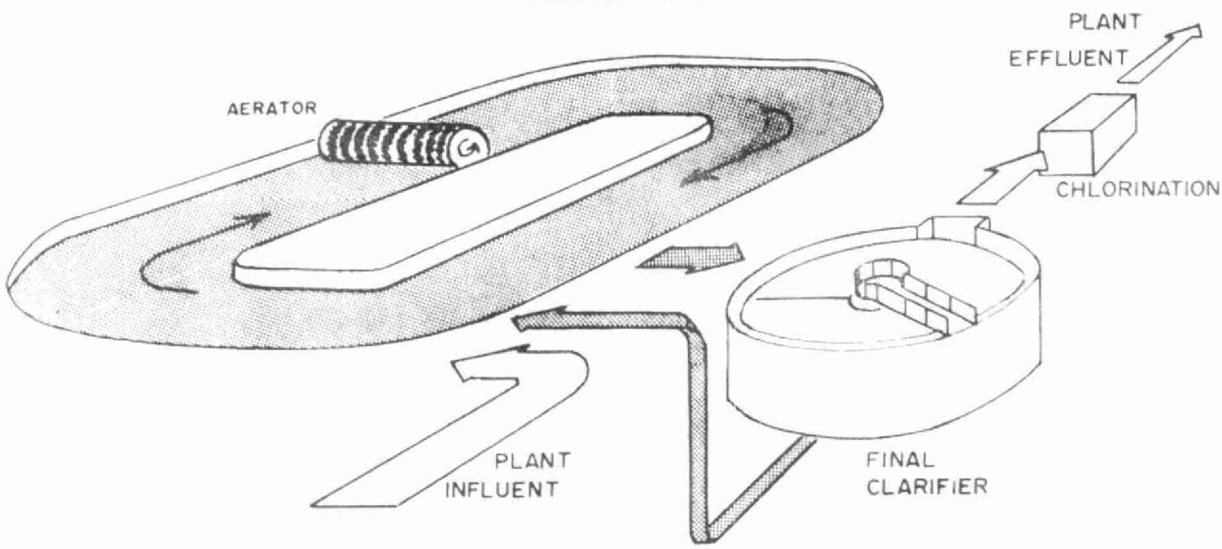
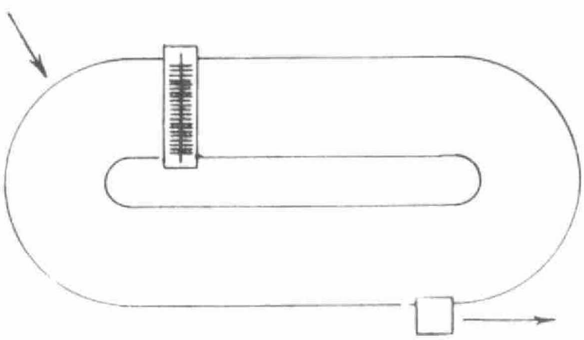
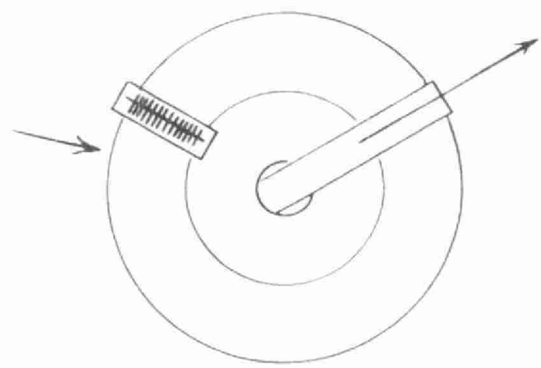


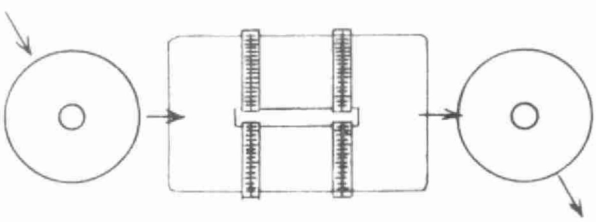
FIGURE 5-3 **OXIDATION DITCH** Shown above as an extended aeration plant. Other possible configurations are shown below.



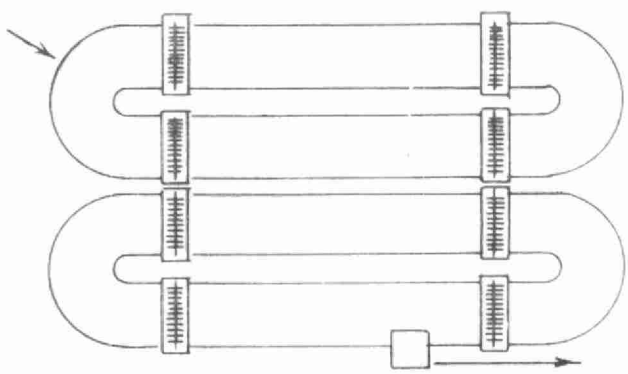
AERATED LAGOON



EXTENDED AERATION PLANT WITH CENTRAL CLARIFIER



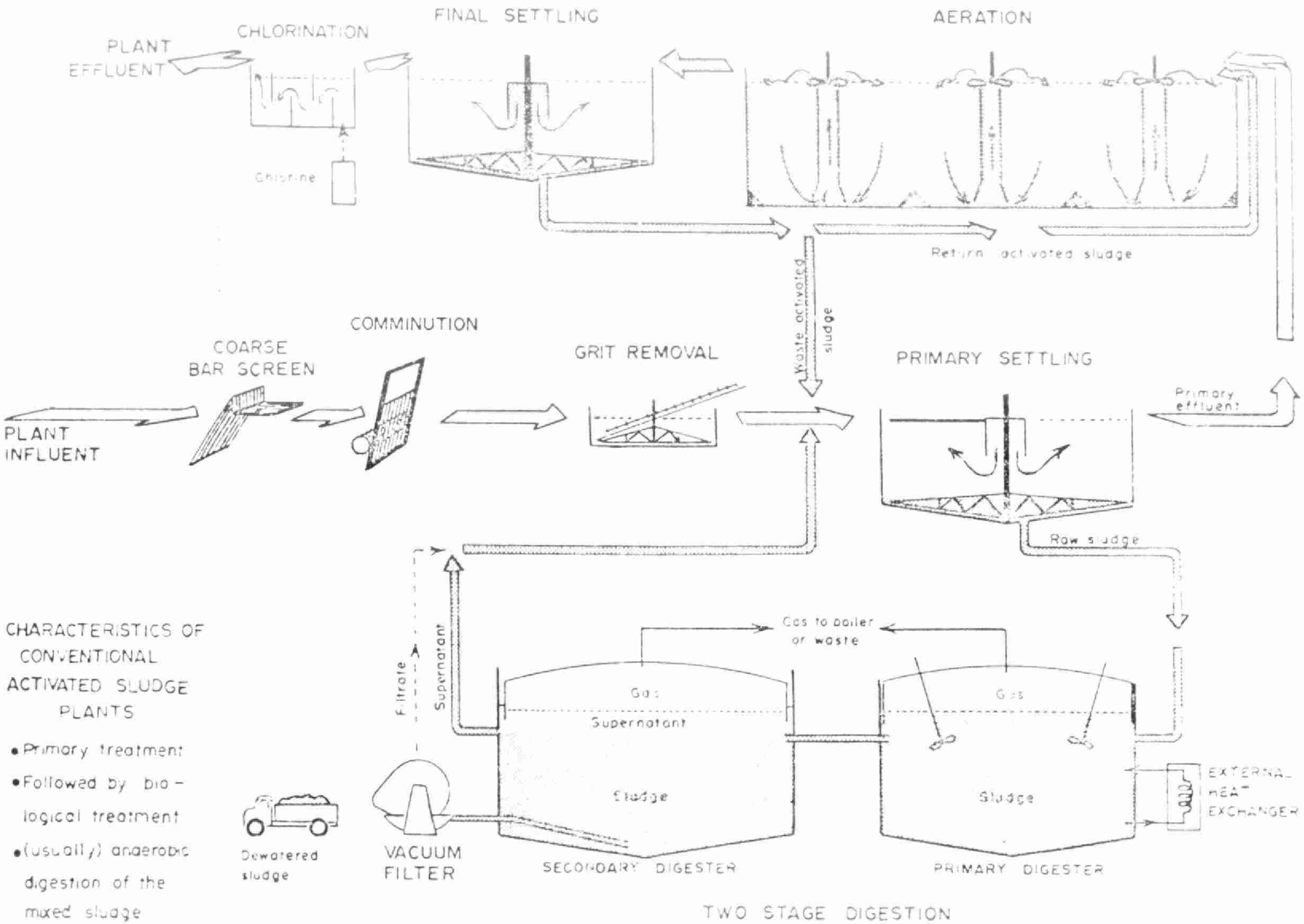
CONVENTIONAL ACTIVATED SLUDGE PLANT



AERATED LAGOON WITH TWO OXIDATION DITCHES IN SERIES

FIGURE 5-4 CONVENTIONAL ACTIVATED SLUDGE

Shown here with circular centre-fed clarifiers, mechanical aerators, two stage sludge digestion, and sludge dewatering by vacuum filtration.



CHARACTERISTICS OF CONVENTIONAL ACTIVATED SLUDGE PLANTS

- Primary treatment
- Followed by biological treatment
- (usually) anaerobic digestion of the mixed sludge

The sub-variation of the conventional process is a process which has no primary clarifier. It consists of an aeration system giving a retention time of approximately 5 hours. With no primary clarifiers, BOD levels of 200 milligrams/litre or more, and all the fat contents (which would normally hamper the activated sludge process) are entering the aeration units. Although this plant is relatively inexpensive to build, it is exceptionally difficult to operate because it does not have the safety factors built in that a conventional plant has and would be suitable only for an installation receiving a very light industrial sewage load. Its use is recommended only for sub-divisions, institutions, or industrial plant pre-treatment.

d) Contact Stabilization or Reaeration

Contact stabilization has many patented names and will be considered in its *reaeration* concept.

This process is considerably different from the others. It has smaller aeration units and a larger final clarifier (Figure 5-5). The raw sewage or primary effluent is mixed with the return sludge for 20 minutes to one hour. In this time the activated sludge *adsorbs* the waste particles. The floc produced is not too dense and passes into a larger final clarifier where the activated sludge and its adsorbed particles are settled. They are then removed to a reaeration tank where the normal *absorbtion process* occurs. Because the return flow is only 30% to 50% of total flow, the reaeration tank need only be half the size of the conventional aeration tank. However, the air requirements are at least as much as that of the conventional process, which is more than 1,000 cu. ft. of air per pound of BOD applied. The *reaeration plant* requires high supervision and is hopefully accompanied by low initial construction cost. With the reaeration process, applied

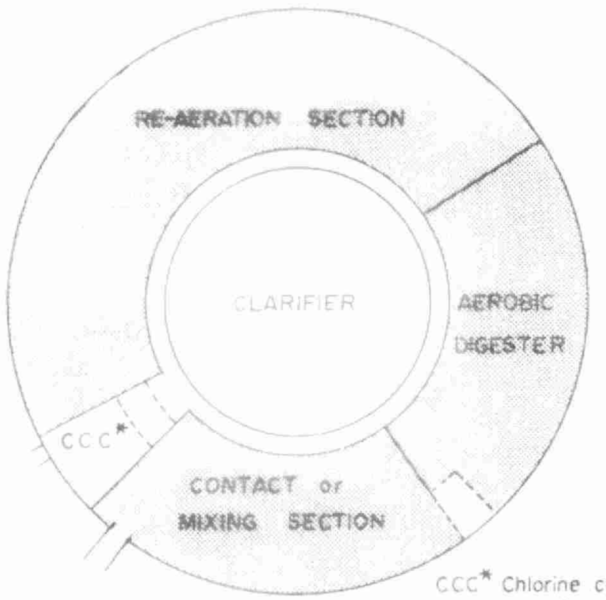


Figure 14. Components are arranged around a central circular clarifier.

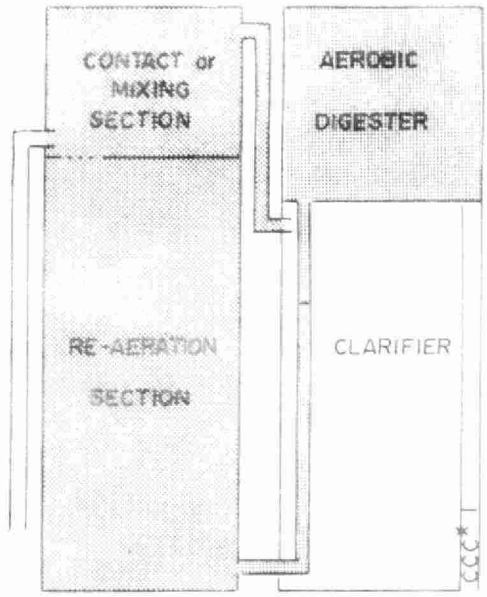
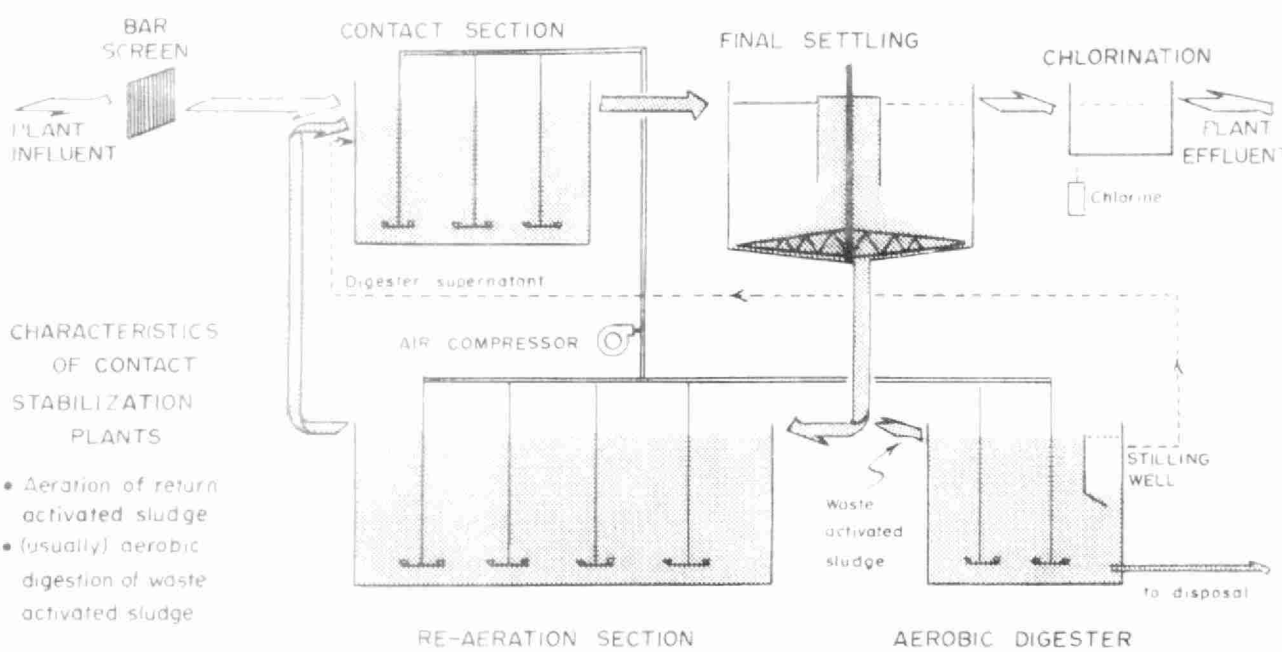


Figure 14b Components are arranged in a rectangular tank.

FIGURE 5-5 CONTACT STABILIZATION

Shown here without grit removal facilities since these are not normally supplied as part of the "package".



CHARACTERISTICS OF CONTACT STABILIZATION PLANTS

- Aeration of return activated sludge
- (usually) aerobic digestion of waste activated sludge

BOD is determined (1,000 cu. ft. of air/lb. BOD applied). The required air is divided between the mixed aeration tank and the reaeration tank. Since the retention time in the reaeration tank is approximately 2 hours and the aeration contact time is one hour, the air must be applied to the total system at a high rate.

The process has certain advantages. A considerable amount of activated sludge is held in reserve and if the monitored raw waste varies, the appropriate amount of sludge can be determined for a balanced F/M ratio. There is also some noticeable saving in the size of structures to be built. Its disadvantages include:

- the need for more pumping and mechanical equipment
- the pumping of more air into a smaller tank requiring more involved air diffusion
- a more competent operator to adjust the process to shock influent loads.

Factory-built plants frequently provide for these requirements in their design.

Lab Tests

To progress from the conventional to the reaeration process, it is necessary to obtain quick information on what is happening. Tests which enable the operator to make quick changes or spot checks on the process efficiency include:

a) *The half hour settling test.* This test gives a complete picture of the process efficiency, especially if it is plotted in a 5-minute interval.

b) Since the available *dissolved oxygen in the mixed liquor* leaving the aeration units can be significant,

a good dissolved oxygen meter is a necessity for quick information.

c) Another meter giving good information is a *pH meter*. With the coming of nutrient removal to the entire province by the end of 1975, pH control is a significant requirement in chemical dosing for phosphorus precipitation.

SUBJECT:

BASIC SEWAGE TREATMENT OPERATION

TOPIC: 6

DIGESTION OF SLUDGE

OBJECTIVES:

Trainee will be able to:

1. Explain the main purpose for sludge digestion.

2. Describe the anaerobic digestion process.

3. List five critical factors in sludge digestion.

4. Describe in sequence the basic procedures for the anaerobic digestion start-up.

5. Describe the following operational steps of single stage digestion:
    - loading
    - process
    - supernatant selection
    - digested sludge removal

6. List in order of importance the various laboratory tests to perform.

7. Describe the following operational procedures of two stage digestion:
    - loading
    - process
    - sludge transfer
    - supernatant selection
    - digested sludge removal

8. Describe briefly the aerobic digestion process.

9. Define the following critical factors:
    - air supply
    - volume of the system
    - tank installation

10. List the seven operating procedures of the aerobic digestion system and explain the significance of each.

DIGESTION OF SLUDGE

PRIMARY PURPOSE

The primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge (removed by sedimentation processes) to a simpler non-objectionable state. Digestion produces a sludge more amenable to dewatering, without nuisance, and renders the sludge fit for easy disposal by lagooning, dewatering on sand beds, and by direct application to farm lands, golf courses, parks, etc. Digestion also reduces the volume of sludge and in doing so produces gas which can be utilized for heating purposes or gas engine operation. Sludge digestion can be either anaerobic or aerobic.

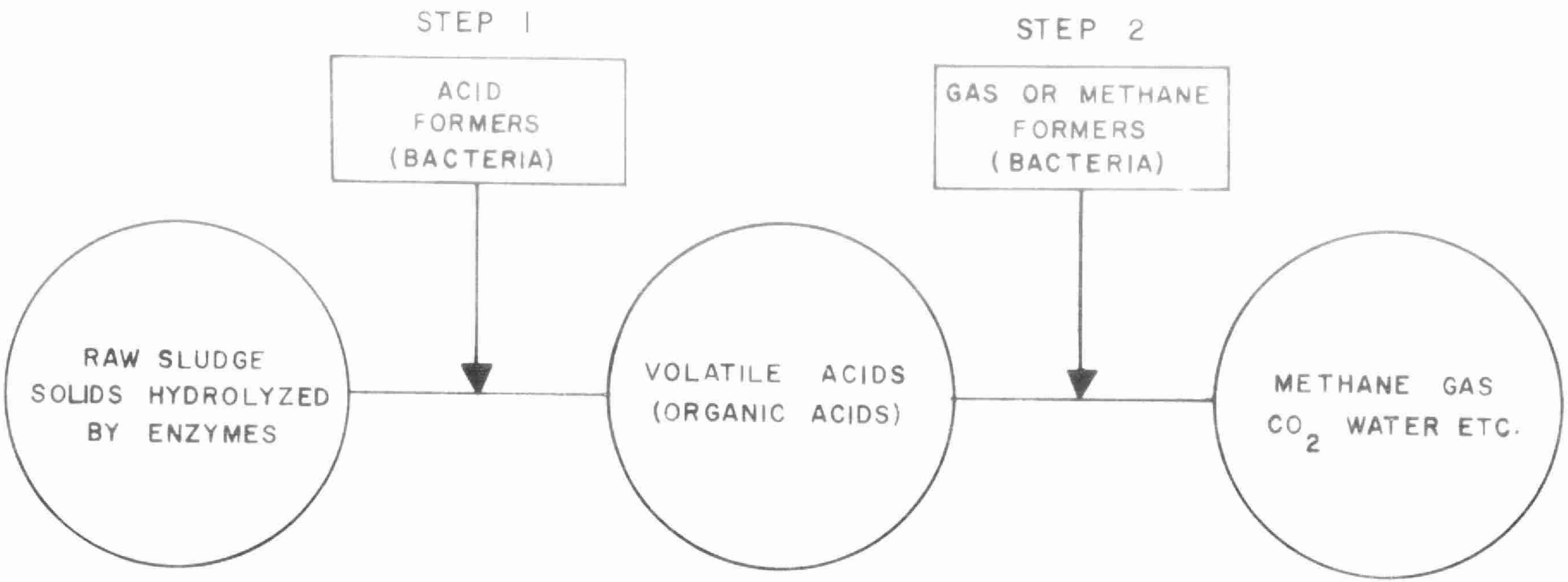
THE ANAEROBIC DIGESTION PROCESS

(In this chapter reference should be made to the two-step process diagram on page 6-2.)

In the anaerobic digestion process, the sludge can be considered as consisting of two portions: a solids portion, composed of material settled in the clarifiers, and a liquid portion, containing materials in actual solution. The concentration of material in true solution is relatively low in raw sludge charged to the digester, and is essentially no higher than that contained in sewage entering the treatment plant. Basically, the dissolved materials are the only ones which the bacteria may utilize as food.

After sludge is sent to the digestion tanks, the organic materials, contained mostly in the solid portion of the sludge, are slowly hydrolyzed and brought into solution by enzymes present in the digester. Under normal conditions of operation, the organic matter is then quickly broken down into volatile organic acids by a group of bacteria commonly called "acid formers". The organic acids are in turn decomposed into carbon dioxide and methane by a second group of bacteria commonly called the "methane formers". Because of this decomposition, the quantity of

ANAEROBIC DIGESTION PROCESS



FAILURE OF STEP 2 WHILE STEP 1 CONTINUES CREATES AN EXCESS OF ACIDS REDUCING PH AND FINALLY CAUSING TOTAL PROCESS FAILURE.

FIGURE 6-1

organic matter actually in solution normally remains low. There is, however, a buildup of certain salts in solution such as ammonium, calcium, and magnesium bicarbonates which result from the breakdown of proteins and soaps. In a digester, these salts produce the natural buffers, which normally remain fairly constant at about 1,000 to 3,000 mg/l as calcium carbonate, dependent on the sludge concentration.

When unbalanced digestion conditions exist, the methane-producing organisms cannot remove the volatile acids as quickly as they are formed and a buildup of the volatile acids results. This buildup can take place very rapidly, and in several days the total concentration of the volatile acids in solution can be more than doubled (see Figure 6-1), and note that failure occurs in the critical second phase when the gas methane forming organisms do not break down volatile acids fast enough.

pH ranges from 6.8 to 7.2 have proved effective in maintaining a good digestion process. Experience has shown that digester process failure will be far advanced before the pH will indicate a problem. The volatile acids test has proved more effective in avoiding a process breakdown. Volatile acid concentrations between 200 mg/l and 500 mg/l will indicate satisfactory operation. A change from 300 mg/l to 500 mg/l might indicate a developing problem but until a concentration of 1,000 mg/l is reached, gas production will remain high.

To prevent a drop in pH caused by an excess of acid, alkaline material such as lime or sodium hydroxide may be added to neutralize the excess acids. The continued use of such neutralizers can cause a process failure because of an ion toxicity factor (Na and Ca ions). Therefore, the actual cause of high volatile acids concentrations must be ascertained and corrected for a successful operation.

CRITICAL FACTORS IN SLUDGE DIGESTION

The success of a digester operation and the causes of process failure depend on the following critical factors:

1. quantity of sludge and digester sizing - overloading or drastic rapid changes in the rate of loading can cause process failure;

2. quality of sludge - toxic materials such as metal ions can cause a process failure;

3. temperature - failure in the operation can be caused by a drop in temperature;

4. mixing - enough space must be provided in the tank for proper mixing;

5. gas production - poor quality gas or a reduction in quantity produced indicate process problems.

1. QUANTITY OF SLUDGE AND DIGESTER SIZING

The quantity of raw sludge will depend upon:

(a) the amount and type of solids in the sewage;

(b) the removal of solids by the sewage treatment processes;

(c) any change in the amount of solids produced by the treatment processes;

(d) the concentration of solids in the sludge to be added to the digestion tanks.

Normally, the suspended solids in a domestic sewage average 0.20 pounds per capita per day. Allowances can be made for industrial waste loadings and figures are available for that purpose.

The removal of suspended solids in the sewage treatment plant varies with the type of sewage treatment and the efficiency of the process as follows:

TABLE 6-1 PERCENT REMOVAL OF SUSPENDED SOLIDS

	Removal Percent
Primary Settling	40 - 60
High-Rate Trickling Filter	75 - 85
Conventional Activated Sludge	85 - 90

The treatment process may increase the amount of solids by conversion of dissolved and colloidal material to setteable solids. Biological processes may reduce the amount of volatile solids by aerobic digestion in trickling filter and activated sludge units.

TABLE 6-2 TEN-STATE STANDARDS OF DIGESTER SIZING

	Cu. ft./Capita	
	Heated	Unheated
Imhoff tanks	--	3 - 4
Primary	2 - 3	4 - 6
Primary + high rate filter	4 - 5	8 - 10
Activated Sludge	4 - 6	8 - 12

Lower digester temperatures require greater volume allowance in the design.

Table 6-2, which is taken from the Ten-State Standards, gives a simple method of evaluating the loading in cu ft per capita of solids directed to a digester. Any drastic change in population and/or the addition of industries requiring water for their process (called "wet" industries) should signal possible problems because of increased loading.

Another loading criteria put forth in the Ten-State Standards, 2 to 3 lbs of solids per month per cu ft of digester volume provides space for sludge storage, and supernatant separation, as well as well as allowing some capacity for overload and a scum blanket.

When only the active digestion volume is considered, new design criteria permit a loading factor of 8 or more pounds of solids each month per cubic foot of digester capacity. The 8 pounds loading factor corresponds

to a ten-day retention period for a sludge of 5% concentration. When using this criteria, only the first mixed-stage of the digestion process is considered. Additional capacity must be added for other factors, such as sludge storage, supernatant separation and overloading.

If the digestion process is compressed into too short a time period, part of the active phase of the process will be transferred to the second stage digestion unit. This will cause supernatant selection and scum blanket problems. Often the second stage digester is not equipped with mixing devices required to control blanket formation.

In smaller installations, the digestion concentrating, and storage functions must be effected in one tank. This type of installation is difficult to operate and seldom can all the necessary functions be carried out as effectively as desired.

In any given digester installation there is a limiting loading rate. Any increase in loading due to the development of new industries and/ or residential subdivisions should be noted. Any drastic change in loading rate over a short period of time should also be noted. Even if the system is sized to handle a much higher loading rate, the bacteria in the process must have the necessary time to develop a more active culture.

2. QUALITY OF SLUDGE

(a) Toxic Wastes

The presence of even trace quantities of heavy metals such as copper can create toxic conditions affecting the rate of digestion. For example, a copper level of 0.5 mg/l in the plant influent can accumulate to a concentration of 125 mg/l in the sludge directed to the digester. While a soluble copper level of 100 mg/l would completely halt the process, part of the copper may be in an insoluble form. This would permit the process to continue operating

but at a reduced level of activity depending on the concentration actually in a soluble form. Other toxic wastes which can prove to be a problem to the digestion process include chrome and nickel.

(b) Grease or Oil

Greases or oils can both overload a system and reduce the active digestion volume by creating an oil or scum blanket. While the additional loading may be a factor the character of the wastes may also prove to be a problem.

3. TEMPERATURE

The digestion process can be effected in the mesophilic range (50 to 100°F) or the thermophilic range (100 to 140°F). In the colder Canadian climate, the unheated digested temperature may drop to 45°F, at which temperature bacterial activity is very low, so all installations should be equipped with heating devices. Heating can be done by outside circulation of sludge through a heat exchanger or by heating coils in the digester itself. Generally, only the first stage digester in a two-stage operation is heated.

The most favourable temperature for sludge digestion (mainly domestic) is 90°F. Lower temperatures may be used depending on the digester capacity available but some margin of safety should be maintained.

In an underloaded system the required temperature may be calculated by assuming that no digestion takes place at 50°F and a maximum rate of digestion at 90°F. A straight line is drawn to connect the two points to enable the determination of the efficiency of the process; for example, at 89°F the process could be considered to be 75% effective. In calculating temperature requirements include a safety factor to handle overloading and possible furnace breakdown.

When using internal hot water coils for heating, the water feed temperature should be maintained below 130°F - a high temperature will encrust the coils with a sludge cake. Excess water makeup requirements will indicate coil leakage and a smaller than normal temperature drop in the circulation coil water may indicate the formation of an insulation sludge layer on the coils. The use of internal heat exchange coils for digester heating is not recommended on all except small installations.

External Heat Exchangers are preferred because of accessibility for maintenance. These units also provide some mixing and at times the raw sludge feed is directed to the recirculation line to be actively mixed with the circulating "seed" sludge. In a system equipped with good internal mixing this point is to some extent redundant.

4. MIXING

The objectives of mixing or recirculation are:

1. Uniform transfer of heat to entire mass.
2. Intimate mixing of raw sludge with seed sludge mass.
3. Prevention of dead areas and scum blankets.

Many systems have been devised for carrying out the above functions. The most satisfactory results are obtained with digester gas recircualtion units or internal mechanical mixers. When these facilities are not available, some mixing is obtained by recirculating digester contents using external pumps. Directing the recirculated sludge to the top of the scum blanket may assist in controlling a scum blanket buildup.

Mechanical mixers can be operated using a timing cycle to attain the required results. In no case should the timing cycle be set with the economic use of power as the only criteria. In an underloaded digester, the mixing units are only operated to prevent the formation of a scum blanket. The draft tube level may be varied to obtain the best results.

The operation of mixers in a single stage digester to provide adequate scum blanket control while obtaining a good supernatant and a concentrated sludge is a problem. Mixing must be discontinued when the supernatant is withdrawn. Therefore, single stage units are to be discouraged.

Where mixing facilities are not provided, alternate means must be developed to remove the scum blanket on a regular basis. Compressed air may be used. For example, a 125 cfm compressor may be used to supply air to mix the contents of the digester and break down the blanket. This should be done at least twice a year and a safety officer should be on hand to ensure that all necessary precautions are taken to prevent a fire or an explosion.

When air mixing is underway the compressor should be located away from the open top of the digester; remove as many of the digester top covers as possible; do not knock steel surfaces together; use non-sparking tools; NO SMOKING should be permitted in the plant area; and the plant gates should be closed to outsiders. The air may be discharged through a one-inch steel pipe (20 feet long) which may be inserted at different points through openings in the top, or the air may be directed through a bottom withdrawal line. It is usually best to remove at least some of the settled solids soon after the mixing is stopped. In difficult cases a new blanket will again form requiring a repeat of the mixing cycle.

With inadequate mixing, a foaming problem may develop. This is caused when a scum blanket commences to digest, thus creating gas. With the blanket being firm the gas bubbles create a foaming condition. This foam may plug gas lines and overflow pipes. The solution to foaming is to reduce the load on the digester and thoroughly mix the digester contents to eliminate the scum blanket. At the same time dilution, pH control, etc. may be required to prevent process failure. This is because a large quantity

of raw or partly digested sludge is added to what may be an already overloaded system.

5. GAS PRODUCTION

A gas production of 15 cubic feet per pound of organic solids destroyed can be expected when the digester is operating normally. The gas will contain 65 to 70% methane and 25 to 30% carbon dioxide. During start up and at the time of process failure, the methane percentage will be greatly reduced. The gas yield from an activated sludge plant can be approximately 1.0 cu ft per day per capita. In an average digestion process, approximately 33% of the total solids and 50% of the volatile solids in the raw sludge are reduced by the process. In more volatile sludges the percentage will, of course, be higher.

The quality of gas may be determined by flame colour; also, poor quality gas (low methane content) will not burn in more complex heating equipment. These factors along with daily checks on the quantity of gas produced will assist in pinpointing process problems.

ANAEROBIC DIGESTER START UP

The following basic procedures are used for anaerobic digester start-up:

1. All construction should be completed before start-up. Alterations and repairs of internal parts are difficult to make once the digester is operating.
2. Fill all lines and tank with water. Raw sewage may be used. Do not use raw sludge as it would overload the process.
3. Add seed material if available. Supernatant or settled sludge from an operating digester is the only product which will be effective.
4. Heat tank contents to 90 to 95°F and maintain at that temperature.
5. Add raw sludge at a rate of .01 pound of solids per cubic foot of digester volume per day for an unseeded digester and a somewhat higher rate, depending on the amount of active material provided, for a well seeded digester. The loading on a high rate process can be .25 pounds of solids per cubic foot per day. The .01 pounds of solids per cubic foot per day is equal to 1,000 gallons of 5 per cent sludge to a 50,000 cubic foot capacity digester.
6. Using available mixing facilities circulate the digester contents and maintain the temperature.
7. Check the process daily by determining the volatile acids and pH. As the volatile acids test is a complex test it may not be possible to do it as often as desired. As the process proceeds the quality of the gas may be checked if the gas testing equipment is available. Also the sludge alkalinity may be determined. Lime may be added to control pH but if the volatile acids approaches 2,000 mg/l the sludge feed is reduced or stopped as required.

   NOTE: Excess lime may inhibit the process.

8. Gradually increase raw solids loading on the basis of favourable trends. The loading must not be increased with volatile acids levels above 1,000 mg/l.

(a) SINGLE STAGE DIGESTION OPERATION

General

Single stage digester operation is covered under four headings:

1. Loading
2. Process
3. Supernatant Selection
4. Digested Sludge Removal

1. Loading

Ideal conditions would be met if the raw sludge could be pumped continuously to the digester. For various reasons continuous loading is not possible. Small plants receiving eight hours per day of operator supervision may load the digester three times a day, say at eight in the morning, 12 noon, and four in the afternoon. Where automatic pumping facilities are provided the other extreme may be reached with loading being effected once each hour. Where supervision is provided on a 24-hour basis, manual control may dictate six to eight pumping cycles per day. Excess water will be directed to the digester if too many pumping cycles are provided. When raw sludge must be pumped for some distance, to the digester, the sludge line must be filled with dilute sludge before the pump is stopped. The next pumping cycle will direct the dilute sludge to the digester.

In a single stage operation the raw sludge is directed to the top half of the digester. As indicated in the flow diagram appended as Figure 6-2, the raw sludge may be mixed with seed sludge leaving the heat exchanger.

2. Process

To maintain the process, two main operating criteria must be met:

(a) Sufficient mixing must be afforded to bring the raw sludge in contact with seed material and also to maintain sufficient area free for the digestion process. Where mechanical or gas recirculation equipment is not available a careful check must be kept on the process to ensure that a foaming condition is not created or that the reaction space left does not become too small. In a single stage unit, mixing facilities, if any, are designed only to mix the material in the top half of the tank. In practise such a design is near impossible. Thus it is difficult to obtain a concentrated sludge from a single stage digester operation.

An improper mixing program could cause a process failure. The active volume available for the digestion process can be greatly reduced by the formation of a scum blanket and sludge banks. Foaming can occur when the scum blanket begins to digest. The scum blanket may be partly controlled by the use of compressed air to mix the tank contents. When using air for mixing great care must be taken to ensure that the explosive air-gas mixture is not ignited. This control measure may be effected two or three times a year depending on need. If just once the designers had to remove the scum blanket from a digester using fire hoses, shovels, etc., they would think twice before designing a digester lacking positive mixing devices. *Be careful* when using air to mix the digester content. Obtain the services of a safety officer. Forbid smoking in plant area, use rubber footwear, use no-sparking tools and do not bang pipe so as to cause a spark at digester openings. Also, open as many manholes as possible for ventilation.

(b) The second process criteria that must be considered is temperature. The ideal operating temperature for mesophilic digestion is between 90 - 95^{O}F. A lower temperature may be used if excess digester capacity is available.

To maintain a check on the process, various tests and records are required. The number of tests required or that can be economically performed at a plant will greatly depend on the equipment available and the size of the plant. Also where good mixing is afforded the chance of process failure is less, and therefore fewer tests would be required. A few of the tests, *listed in order of importance*, are as follows:

1. volatile acids,
2. temperature,
3. scum blanket depth,
4. supernatant suspended solids,
5. pH,
6. alkalinity,
7. gas compositions,
8. raw and treated sludge composition, volatile and total solids.

Records can also be kept of:

sludge directed to digester,
sludge removed from digester,
quantity of gas,
mixer operating schedule.

3. Supernatant Selection

It is difficult to obtain a good supernatant from a single stage digester. Nevertheless, an attempt should be made to remove excess liquid. Where mechanical mixing is practised, the mixing devices are shut off for a period of time before the supernatant is withdrawn. Experience will show the quiescent period required to obtain a good supernatant.

When a variable level supernatant selection is provided the supernatant is removed via the line proving to be most satisfactory. An example of a supernatant selector system is appended as Figure 6-4. Withdrawal control is maintained in simpler installations by a sleeve height adjustment. Other installations use valves to control the withdrawal process. In all installations a safety overflow should be kept open at all times.

The suspended solids test is used to check on the efficiency of the withdrawal process. The actual test can be determined using a centrifuge for quick results, and the standard suspended solids test where complete laboratory equipment is available. The raw sludge directed to the digester may have a suspended solids concentration of 30,000 to 60,000 mg/l. Therefore, the supernatant suspended solids concentration should not be allowed to approach this figure or little headway will be made in the overall plant operation. A suspended solids concentration of 1,000 to 3,000 might be considered permissible with the ideal level being below 500 mg/l.

4. Digested Sludge Removal

The accumulated sludge should be removed as frequently as possible. It will be difficult to obtain a concentrated sludge from a single stage operation. A 3% to 4% sludge may be considered good for the digested sludge obtained from an activated sludge plant utilizing a single stage digestion process.

When the gas is utilized from a fixed cover operation, the digested sludge is best removed when the raw sludge is being pumped. This practise will assist in maintaining the gas pressure.

Bottom withdrawal line and depth samples are tested to control the sludge withdrawal process. The total and volatile solids tests are two criteria used to evaluate the stability of the sludge and its concentration, as per economy.

(b) TWO STAGE DIGESTION

General

Two stage digestion is covered under five headings:

1. Loading
2. Process
3. Sludge Transfer
4. Supernatant Selection
5. Digested Sludge Removal

1. Loading

When high rate complete mixing is practised the raw sludge may be directed to any point in the first stage tank. Otherwise the loading procedure is similar to that used for the single stage operation.

A good two stage design will allow the use of either tank for the first stage or heated unit. An example of **a** two stage digester flow diagram is given as appended Figure 6-3.

2. Process

Where mixing devices are available they are operated to control scum blankets and inactive dead spaces. Most of the mixing is effected in the first stage tanks. Often mixing units are not installed in the second stage tank. The mixing devices may be operated either full or part time. When part time operation is desired the cycle is set up in relation to tests and observations of scum blanket formation and not on power saving. In some operations the mixers may only be used a few hours a day.

An improper mixing program could cause a process failure. The active volume available for the digestion process can be greatly reduced by the formation of a scum blanket and sludge banks. Foaming can occur when the scum blanket begins to digest. The scum blanket may be partly controlled by the use of compressed air to mix the tank contents. When using air for mixing great care must be taken to ensure that the explosive air-gas mixture is not ignited. This control measure may be effected two or three times a year depending on need. If just once the designers had to remove the scum blanket from digester using fire hoses, shovels, etc., they would think twice before designing a digester lacking positive mixing devices. Be careful when using air to mix the digester contents. Obtain the services of a safety officer. Forbid smoking in plant area, use rubber footwear, use no-sparking tools and do not bang pipe so as to cause a spark at digester openings. Also, open as many manholes as possible for ventilation.

Heating units are used to heat the contents of the first stage digestion tank. Optimum mesophilic digestion is carried out at between 90 and 95°F. However, lower temperatures may be used where excess digester capacity is available. The maintained temperature should be such as to provide some safety factor.

3. Sludge Transfer

Sludge can be transferred from the first stage digester by a number of means, three of which are as follows:

(a) Automatic transfer may be effected using an equalizing line, as shown on appended flow diagram, Fig. 6-3.
(b) Sludge may be transferred using the heat exchange unit recirculating line,
(c) Bottom sludge may be pumped to the second stage unit.

The transfer program should be set up to delay the removal of solids from the first stage unit. If possible top material is transferred when the mixing devices are off. Nevertheless frequent transfers, at least once a week, must be made from the bottom of the first stage tanks. If this is not done the bottom withdrawl line will plug with grit and solids.

4. Supernatant Selection

The supernatant is obtained from the second stage digester. The supernatant can be selected automatically when a sludge transfer takes place or as an operating procedure when the plant can best receive the extra BOD loading. The type of selectors provided will of necessity partly dictate the program to be chosen.

5. Digested Sludge Removal

In a fixed cover installation the sludge must be removed in small batches. If this is not done the gas pressure will not be maintained.

When at least one floating cover is provided the sludge settled in the second stage unit may be removed as convenience requires; large withdrawals will not cause process failure or a loss of gas pressure.

Sludge samples should be collected as indicated for the single stage operation. A two stage operation will provide a more concentrated sludge.

EXAMPLE

An example of a process failure in an operating digester will be reviewed. Coverage will be given to the steps taken to return the digestion process to a normal alkaline digestion state.

A review will be made of tests required to control the digester process. Minimum tests required at a small plant and also those required for a large operation will be noted.

FAILURE AND RECOVERY OF DIGESTION PROCESS

The example outline occurred at an activated sludge sewage treatment plant serving a city having a population of 20,000 persons. The raw sewage contained a high percentage of industrial waste waters mainly from a meat packing plant. The necessary sewage treatment plant detail is presented in tabular form.

Plant Loadings During 1961

Average flow to plant	2.62	mgd
Average BOD of plant influent	311	mg/l
Average BOD loading	8150	lbs/day
Average BOD removal by plant	7600	lbs/day
Average suspended solids in plant influent	267	mg/l
Average suspended solids loading	7000	lbs/day
Average suspended solids removed by plant	6300	lbs/day
Calculated volatile solids loading to digester	4200	lbs/day
BOD population equivalent	48,000	persons
Actual population	20,000	persons

Digester Detail

Digester liquid capacity

1st stage .... 67,000 cu ft

2nd stage .... 33,000 cu ft

total .... 100,000 cu ft

Mixing, gas recirculation, 30 cfm compressors

Boiler Capacity 432,000 BTU's per hr

Digester Loading

Cu ft of digester capacity per capita	Actual	Recommended
1st stage	3.3 cu ft	3-6 cu ft
complete	5.0 cu ft	
Pounds of solids to first stage digester per month	3.0	2-3
Cubic feet of digester volume per pound of volatile solids per day to the first stage digester	16	25

Most digester installations are designed with a generous safety factor. The volume in a digester usually exceeds the need and if adequate mixing and temperatures are supplied minor overloading will not cause a process failure. With this example the actual loading approaches recognized design factors. However, normal loading does not approach that allowed in a high rate design.

The table title operating data, appended as Item 1 and 11, contains information on the volatile acids level, raw sludge loading, pH, gas production and operation. During the period review the digester temperature was maintained at 90°F and adequate mixing was carried out.

Process Failure

On November 25, unknown to the plant operator, a load of ether soluble material was discharged to the tributary sewer system. It is believed that the resultant heavy load on the digester system caused an increase in the volatile acids level and finally a process failure. The volatile acids tests failed to indicate the impending process failure and the first major sign was a reduction in the gas production. Also, the burning quality of the gas made it unsatisfactory for boiler use. The volatile acids test was investigated on December 4, and found to be in error.

With the use of new reagents the volatile acid level was found to be 3,280 mg/l. This figure is much above both the average operation range of 200-500 mg/l, and much quoted maximum allowable of 2,000 mg/l. It is noted that

digestion may take place at a volatile acids level of 3,000 mg/l but many factors such as ion toxicity and pH will determine the recovery rate.

Plan of Process Recovery

When a digestion process failure has occurred, indicated by low gas productions, poor quality gas, and an elevated volatile acids level, the operator must organize a recovery program. In setting up this program the most important step is that of ascertaining the reason for the process failure. There is no use in spending time and monies in re-establishing an alkaline anaerobic digestion process if the failure is to recur at a later date. The process failure can be caused by one or a combination of the following reasons:

1. overloading,
2. inadequate temperatures,
3. inadequate mixing, and/or
4. metal ion or chemical toxicity.

In the example under review the probable cause for process failure was short-term overloading. The offender could be cautioned and asked not to batch discharge excess quantities or organic material to the sewer system. Possibly an interceptor grease trap is required on the company's outfall sewer.

After the cause of the failure is thought to be known and corrected, a plan of recovery should be outlined. Possible recovery programs are;

1. the removal of all the liquid and sludge from digester and the restart of a new digestion process;
2. the removal of part of digester contents for the purpose of reducing the volatile acids level by dilution and at the same time the raw sludge loading is reduced or completely stopped.
3. the addition of lime for pH adjustment while reducing or eliminating further raw sludge loading; or

4. the reduction of the raw sludge loading to the digester.

1. Remove Sludge from Digester

This step is drastic and it may require a period up to two months to re-establish active digestion. The disposal of sour sludge from a digester is a major job in itself and then seed sludge must be obtained to speed the digester start-up process. In the meantime a large portion of the raw sludge must be hauled for farm or other disposal. On the other hand, the process failure may be so complete that ineffective half hearted solutions will only waste time.

2. Removal of Part of Digester Content

The dilution of the sour digester contents with raw sewage, not sludge, will reduce the volatile acids level. In using this method of solution active digestion agents will remain. Again the raw sludge is redirected to another method of disposal and should not be returned to the digester until the volatile acids level is below 1,500-1,000 mg/l. Full loading is not attempted until the volatile acids level is reduced below 750 mg/l.

Below a given volatile acids level the recovery process will be dramatic while above 2,000 mg/l progress may be slow. In the 1,000 to 1,500 mg/l range very active digestion may occur and unless adequate mixing is provided foaming can result.

3. pH Adjustment

In the given example the pH did not drop below 6.8, therefore pH adjustment would not aid in improving the digestion process. Also pH adjustment could cause an ion toxicity problem.

When the pH is below 6.8 some adjustment is in order but care should be taken that the true cause of the failure is first eliminated. As in the dilution method outlined above raw sludge loading must be discontinued.

4. Reduced Loading

When the digestion process failure is not complete the most satisfactory method of recovery consists of the

complete or part removal of the raw sludge load. As previously stated the reloading is commenced when the volatile acids level drops below 1,000-1,500 mg/l. Complete reloading should wait until the volatile acids level is below 750 mg/l.

Review of Example

In the example under consideration it was believed that the failure was caused by overloading. When the gas would not burn in the boiler sludge pumping was discontinued. The pH was satisfactory at 6.8 to 7.1 so lime was not added. As gas was being created and the volatile acids level did not rise above 3,300 mg/l it was decided to follow the reduced loading technique. This approach appears to have been effective and a complete process recovery was achieved in approximately 20 days. The recovery program varied slightly from the idea and raw sludge was pumped to the digester in small quantities before the volatile acids concentrations reached the 1,000 to 1,500 mg/l level. This action would tend to delay recovery. On the other hand the reloading program might have been accelerating when the volatile acids level dropped below 750 mg/l. The full load return should not be attempted in one day.

The process recovery achieved at this plant was well planned and carried out. The operator had the benefit of:

(l) a holding lagoon isolated from housing where excess sludge could be directed during period of process failure;

(ll) good laboratory facilities and the time and ability to carry out the difficult volatile acids and other tests;

(lll) a digester system with adequate mixing so that the scum blanket and inactive process areas could be kept to a minimum;

(lV) adequate boiler facilities which enable satisfactory temperatures in the digester.

On the other hand the two stage digester system at this plant is constructed in one unit which prevents

flexible operation. In a plant having separate digesters the raw sludge can be directed to the second stage digester while the first stage unit is rested and returned to satisfactory condition. Excess raw sludge had to be removed from the holding pond first thing in the spring or an odour problem could have been created.

CONCLUSIONS

The example reviewed pointed out the need for accurate laboratory control over the alkaline anaerobic digestion process as used for sludge reduction and stabilization in a sewage treatment plant. The other alternative is to have complete control over:

BOD loading
mixing
heating
industrial wastes

The example under review confirmed the premise that the pH test is of little use in forecasting process failure.

In a small plant the loading factor could be reduced thereby offsetting the effect of a part alternation of one of the four affecting factors. When a town does not contain chemical or metal plating industry the BOD loading is the only instantaneous unknown. The heating and mixing functions are of course effectively measurable.

In a large plant where high loading factors are used the minimum required laboratory tests for digester operation are:

volatile acids
alkalinity
pH
gas composition
raw sludge dry solids, total and volatile
supernatant dry solids and BOD
digester sludge dry solids, total and volatile

In a smaller plant lacking laboratory equipment and having an oversized digestion system the volatile acids and other tests will have to be carried out at a central laboratory. The plant itself can keep accurate data on sludge pumping and wasting, mixing schedules, and heating.

With the knowledge we have of the alkaline anaerobic digestion process there should be few unforecast process failures. Also, if a failure does occur we should be able to plan an effective recovery program. This program may prove to be costly but half measures will only lead to failures and further expenses.

THE AEROBIC DIGESTION PROCESS

The aerobic digestion process is an extension of the extended aeration process where the volatile material in the wastes is destroyed to a reasonable maximum with up to a 45% destruction of volatile solids. The aerobic digester is a separate operation in which concentrated sludge, haveing 3-6% Mixed Liquor Suspended Solids is processed. The decomposition of solids and regrowth of organisms is maintained until the available energy in active cells and the storage of waste materials are sufficiently low and stable enough for disposal.

CRITICAL FACTORS IN PROCESS

The aerobic digestion system is simple to operate and maintain when compared to the anaerobic digestion process.

The most critical factors include:

1. Air supply;
2. Volume of system;
3. Tank insulation.

1. Air Supply

An air supply of 20 cu ft/min per 1,000 cu ft of digestion tank volume was originally suggested for aerobic digestion. This level of air feed, however, has not proven to be effective in keeping solids in suspension and maintaining a 1 mg/l oxygen level in the digesters. It is now suggested that the air supply should approach 50 cu ft/min per 1,000 cu ft of tank volume. In a conventional activated sludge plant, this air supply would be nearly twice the amount of air required in the aeration tanks.

2. Volume of System

The system is sized to maintain a minimum sludge age of 45 days. If complete stabilization is desired, the total sludge age could be as high as 120 days. In using the 120 day criteria the sludge age in the regular plant itself may be added to the sludge age of the aerobic

digesters. An aerobic digester system having a sludge age design factor of 45 days would have a tank volume equal to the volume of the conventional aeration tanks sized to provide 8 hour detention. Since the MLSS may be maintained at a 3-6% level in the second stage of a two-stage system a smaller volume is possible with the two-staged unit.

3. Tank Insulation

In the colder Canadian climate, steps should be taken to retain the heat in the aeration tanks. For this reason open steel tanks built above ground are not recommended. To reduce heat loss, a common wall construction with existing tanks in the plant and earth filling around the remaining walls is recommended. Additionally, long above-ground air pipes should be insulated.

GENERAL

While the operator may have little control over the discussed design factors, he should be aware of system limitations if he is to effectively manage the system he is responsible for and encourage improvements.

OPERATION AEROBIC DIGESTER SYSTEM

Operating procedures for the aerobic digester system will be considered as follows:

1. System start up;
2. Sludge feed program;
3. Supernatant control;
4. Transfer program;
5. Processed sludge removal;
6. Air control and records;
7. Scum control.

1. System Start Up

Fill the first aerobic digester tank within three feet of the top with water (use primary or plant effluent or clear water, *not sludge*). Add seed activated sludge

from return sludge flow. Pump raw sludge from primary. Maintain the dissolved oxygen level at 1.0 mg/l (or more).

Each day shut off the air system to allow the solids to settle; decant the supernatant to the plant influent.

Continue to pump in sludge from the plant. Excess activated sludge should be wasted to the primary clarifier two hours before pumping is undertaken (this directs fresh activated sludge to digester). Where there is no primary clarifier, the excess sludge is wasted directly to the digester.

When solids have reached a MLSS level of 10,000 to 15,000 mg/l, the sludge settles to approximately 50% of tank volume. Fill the second stage aerobic digester tank within three feet of top with primary or secondary effluent, then transfer sludge from the bottom of the first stage digester to the second stage tank. Decant the supernatant as required to maintain capacity for additional loading.

2. Sludge Feed

Pump sludge to the first stage digester according to the established plant program. If the plant has a primary clarifier, the waste MLSS should be directed to the primary clarifier two hours before the sludge pumping cycle begins. Sludge cannot be pumped when the digester is in the supernatant removal phase. Also, a plant not equipped with a primary clarifier must pump excess return activated sludge directly to the digester.

3. Supernatant Control

Shut down the air supply to allow the MLSS to settle. The time required will depend on the settleability of the solids. Then draw off supernatant from a point below the surface. The shut-down time should be short to eliminate possible problems.

4. Transfer Program (2 and 3 stage systems)

Sludge is concentrated and transferred as required from the bottom of the first stage unit to the second stage unit. This transfer is not necessarily done each day. Remove sufficient supernatant from the second stage tank to allow the transfer to proceed. In a three-stage system, the first stage air supply is seldom shut down. Therefore, the supernatant is only removed from the final two stages.

5. Processed Sludge Removal

The processed sludge is removed from the bottom of the final stage for land disposal with tank trucks or it is directed to sandbeds or sludge lagoons in isolated small plant operations.

6. Air Control and Records

Feed sufficient air to keep solids in suspension and a minimum oxygen level of 1.0 mg/l in all tanks.

Records can be kept of sludge directed to the system and sludge removal. A centrifuge should be used to determine sludge concentrations in the raw feed, in each tank, the digested sludge and the supernatant. Laboratory tests, mixed liquor suspended solids (MLSS) and volatile solids should be obtained as required to check the process operation.

7. Scum Control

Excess scum should be removed manually from the surface of the tanks on a regular basis.

SINGLE STAGE UNIT.

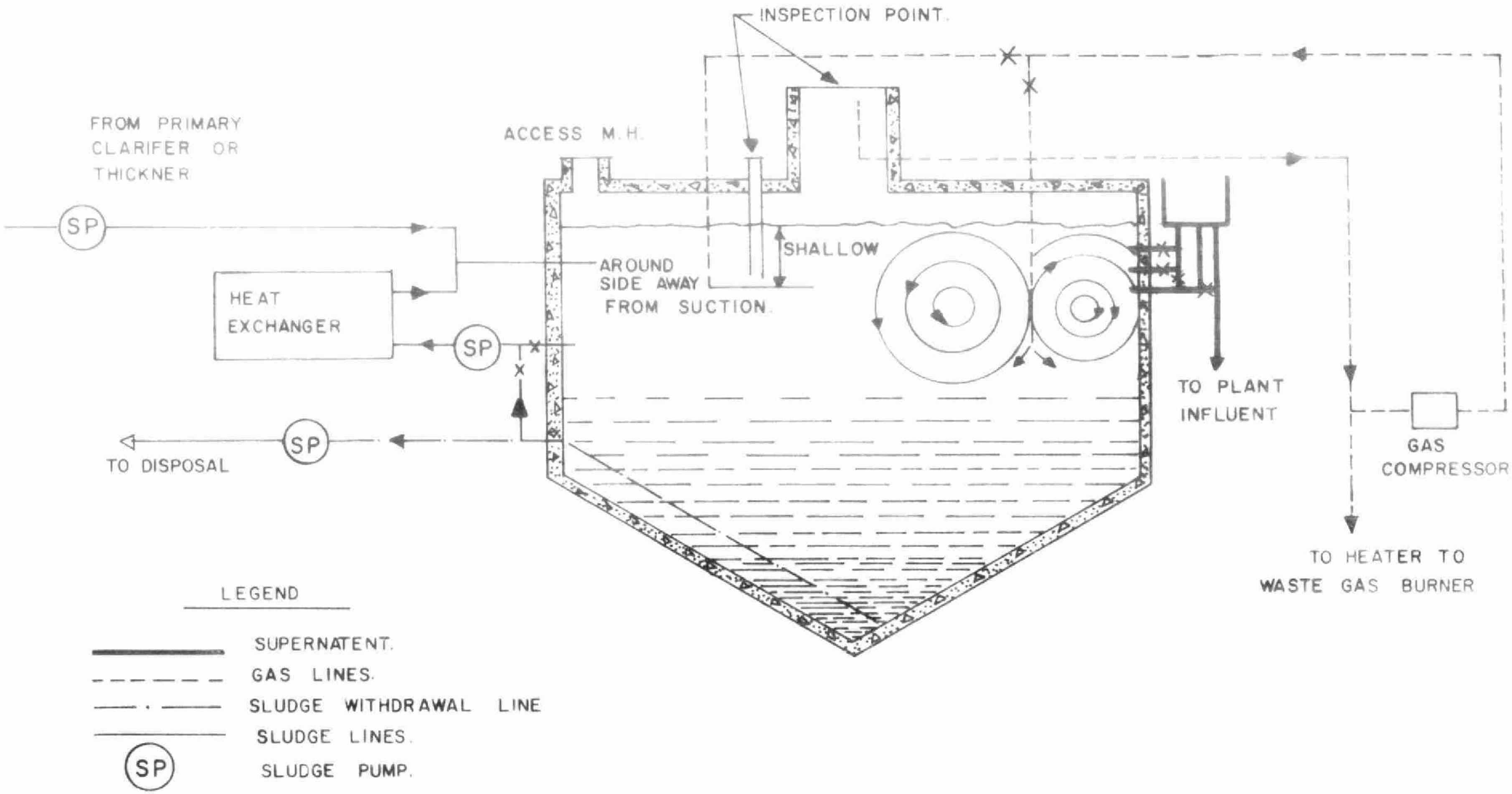
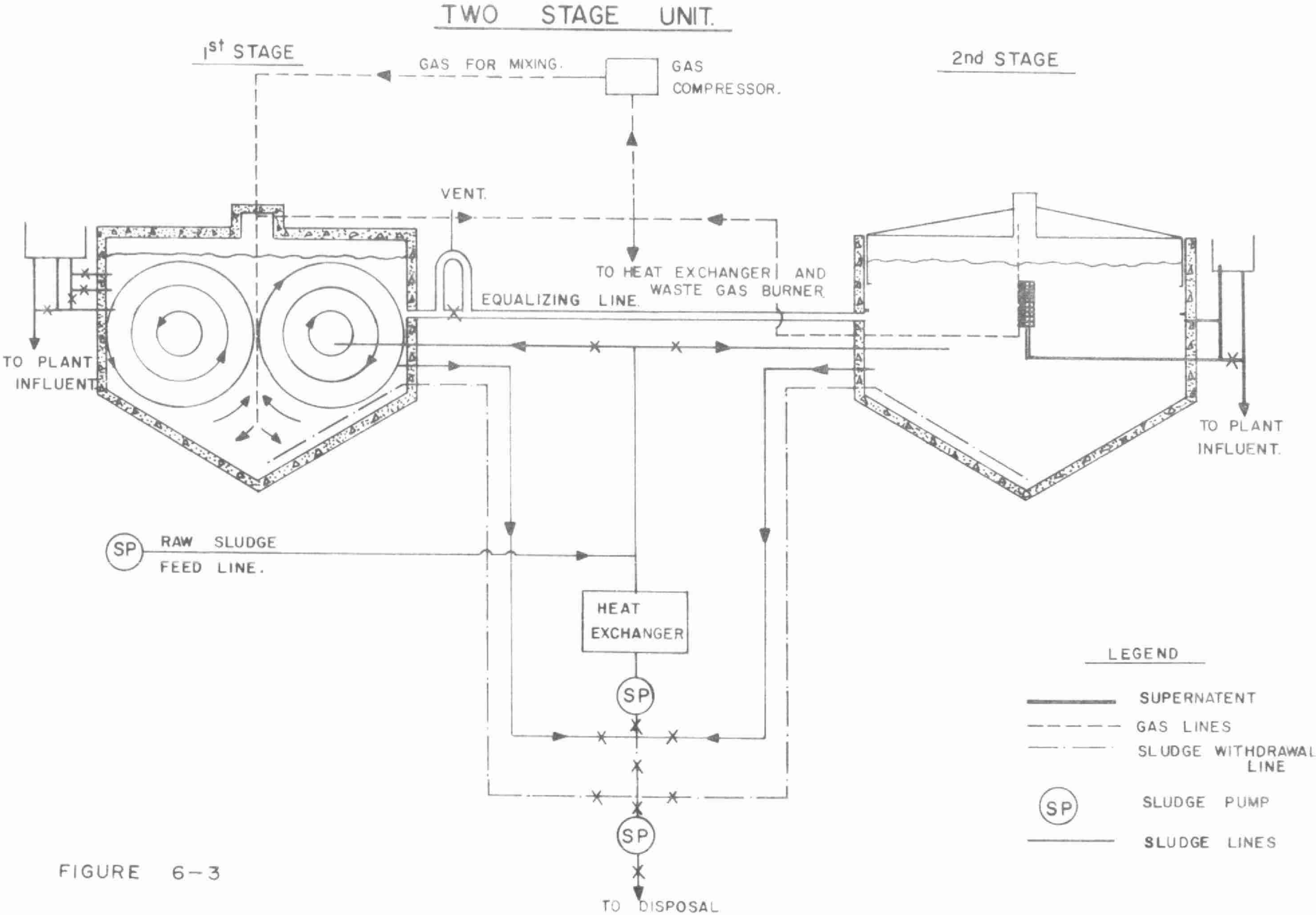


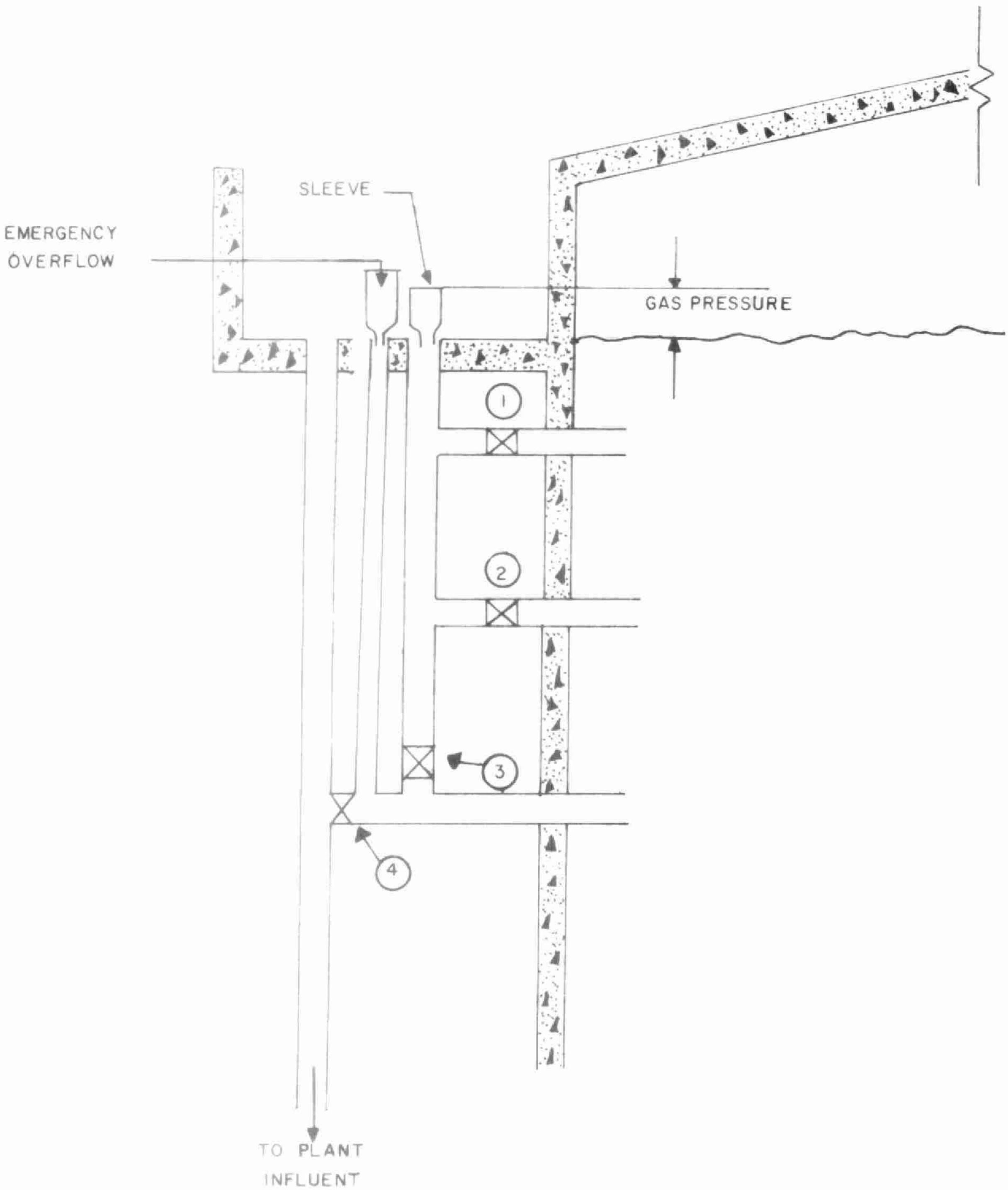
FIGURE 6-2



TWO STAGE UNIT.
1st STAGE
2nd STAGE
GAS FOR MIXING.
GAS COMPRESSOR.
VENT.
TO HEAT EXCHANGER AND WASTE GAS BURNER
EQUALIZING LINE.
TO PLANT INFLUENT.
TO PLANT INFLUENT.
SP
RAW SLUDGE FEED LINE.
HEAT EXCHANGER
SP
SP
TO DISPOSAL
LEGEND
SUPERNATENT
GAS LINES
SLUDGE WITHDRAWAL LINE
SP
SLUDGE PUMP
SLUDGE LINES

FIGURE 6-3

FIGURE 6-4



SUPERNATENT SELECTOR

OPERATING DATA

COVERING PERIOD OF DIGESTION PROCESS FAILURE AND RECOVERY

DATE	VOLATILE ACIDS IN P.P.M.	RAW SLUDGE LOADING IN GALLONS	PH	DIGESTER GAS PRODUCTION IN CUBIC FEET	COMMENTS
NORMAL OPERATION	200-500	7,000	6.8-7.2	200,000 -	
NOV. 25 TO DEC. 4	641-1,086*	-	6.8-7.1	-	LOAD OF ETHER SOLUABLE MATERIAL RELEASED TO SEWERS ON NOV. 27
NOV. 27	-	-	-	9,211	GAS WOULD NOT BURN IN BOILER RAW SLUDGE PUMPING DISCONTINUED
DEC. 4	3,280	1,135	-	1,290	*REAGENTS USED IN VOLATILE ACIDS TEST FOUND TO BE UNSATISFACTORY THEREFORE PREVIOUS TESTS NOT ACCURATE
DEC. 5	3,192	1,000	7.2	902	
DEC. 6	3,226	1,021	7.2	1,419	
DEC. 7	3,381	1,000	7.5	5,002	
DEC. 8	3,385	1,154	7.4	9,210	GAS WOULD BURN IN BOILER BUT HEAT VALUE LOW AND BOILER WATER TEMPERATURE DROPPED 20°
DEC. 9	-	1,000	-	14,064	
DEC. 10	-	1,000	-	17,101	
DEC. 11	1,899	1,015	-	16,065	GAS USED IN BOILER AND HEATING VALUE HAD RETURNED
DEC. 12	1,596	2,000	-	15,649	RAW SLUDGE PUMPING DOUBLED TO 2,000 G. P. D.
DEC. 13	1,407	2,075	-	15,342	
DEC. 14	1,047	2,002	7.4	14,908	
DEC. 15	-	2,002	-	12,730	SLUDGE REMOVED FROM DIGESTER FOR ONE HOUR
DEC. 16	-	3,000	-	13,840	
DEC. 17	-	3,533	-	12,297	
DEC. 18	704	3,950	7.9	-	DIGESTED SLUDGE REMOVED FOR 1.25 HOURS
DEC. 19	704	3,375	7.9	15,350	DIGESTED SLUDGE REMOVED FOR 2.30 HOURS
DEC. 20	453	3,825	7.8	17,515	
DEC. 21	240	4,500	7.2	16,709	
DEC. 22	-	6,200			
DEC. 23	292	-	7.0	21,472	ALL RAW SLUDGE PUMPED TO DIGESTER
DEC. 24 TO DEC. 28	200-300	-	7.0-7.2	16,000-22,000	GAS BURNS WELL YELLOW ORANGE FLAME

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 7

SLUDGE HANDLING METHODS

OBJECTIVES:

Trainee will be able to:

1. Describe what sludge is and name its sources in the waste treatment process.

2. List the concentration in per cent of solids expected in:
   - raw primary sludge
   - waste activated sludge

3. List three factors which determine the quantities of sludge produced.

4. Describe the following methods used to dewater sludge:
   - drying beds
   - vacuum filtration
   - centrifuging
   - sludge lagoons

5. Determine those factors that influence the selection and use of chemicals for flocculation.

6. Discuss advantages and disadvantages of sludge haulage.

7. Describe at least 5 methods of final sludge disposal.

SLUDGE HANDLING

INTRODUCTION

What is sludge? Sludge is the residue resulting from the removal of dissolved or suspended material during the treatment of water and wastewater. Sludges are usually identified in terms of the treatment process in which they originate, ie. raw sludges from primary sedimentation, digested sludges from aerobic and anaerobic digesters.

It must be remembered that there are only three practical places to dispose of sludge after it has been rendered innocuous: air, land or the oceans, unless you consider the moon or outer space as the fourth. Even now the vast oceans' assimilative capacity is not infinitely large and has emitted warning signs.

Sludge Concentration

Sludge concentration is defined as the reduction in moisture content of a sludge in order to decrease sludge volume while still maintaining its fluid properties. By this definition the purpose of sludge dewatering is excluded because the purpose of dewatering is to reduce the liquid sludge to a relatively dry cake. To a limited extent sludge concentration occurs in most clarifier operations, however, this is not the purpose of the clarifier and the concentration of solids in sludge is best carried out in a separate unit.

It must be remembered that if there is initially less water in a sludge then the disposal of this sludge will be less costly. When trying to concentrate sludge in the clarifier one must remember that most pumps are not designed to carry sludge which has total solids concentrations of greater than 10 per cent. Waste activated sludges characteristically have concentrations of only 0.5 to 1 per cent (%). A reduction in volume by concentrating to

3-4 per cent (%) would be significant. Such sludges are quite fluid and easily pumped. Raw primary sludges normally have concentrations of 5 per cent or higher and separate sludge concentrations are not economical.

Sludge Quantities

It is necessary to know the amount of sludge that can be produced at a sewage treatment plant for design requirements, budget requirements and for process control and efficiency. The volume of sludge that is produced is dependent on a number of factors, three of which are listed below:

1. Raw sewage strength and quantity,
2. Type and degree of treatment provided,
3. Type and degree of sludge treatment.

The sewage strength is normally measured in terms of BOD and suspended solids concentrations. These measurements can be affected by such parameters as the type of industries on the sewage system, the degree of infiltration into sewers, and the consumption of water per capita. For a normal domestic waste, the loading on a plant can be estimated by allowing 0.17 pounds BOD and 0.20 pounds suspended solids per capita per day.

The degree of treatment that a sewage treatment provides will affect the quantity of sludge produced. The following table lists the removals expected at various types of plants:

EXPECTED REMOVALS

Type of Plant	BOD_5	S.S.
Primary Sedimentation	30-60%	50-60%
Single Stage Low Rate Trickling Filter	80-90%	80-90%
Conventional Activated Sludge	85-95%	85-95%

For the purpose of this lecture and without considering the more exotic forms of sludge treatment, we can consider that sludge is either digested or it is not. As a general rule, digestion provides for approximately a 40 to 60% destruction of the volatile solids but this percentage can be higher. This destruction, of course, is dependent on such factors as mixing, temperature, detention time, and the initial volatile solids content of the sludge. The volatile solids content of the sludge can range from 60 to 85%.

One should note that in a conventional activated sludge, excess (or waste) sludge is produced and must be disposed of. The quantities generated depend, in part, on a relationship between the oxygen available, the concentration of organisms and the organic load. However, this aspect of sludge production is beyond the scope of this lecture and will not be discussed further.

Example 7-1

Assuming that the following waste characteristics are received at a primary treatment plant calculate sludge quantities at various stages:

Type of waste	-	domestic sewage
Flow	-	2.2 MGD
BOD	-	200 mg/l (ppm)
S.S.	-	200 mg/l (ppm)

Assuming 50% removal of suspended solids, we have:

$$\frac{50}{100} \text{ x } 200 \text{ ppm x } 2.2 \text{ MGD x } 10 \text{ lb/gal}$$

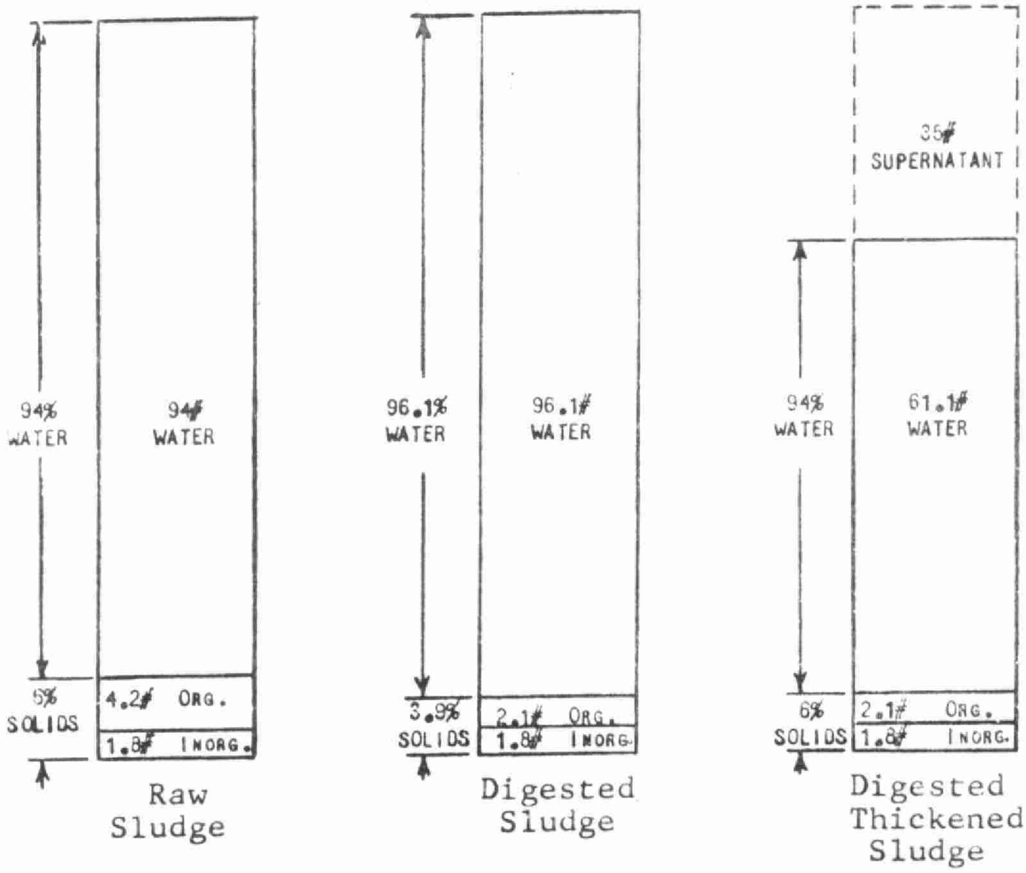
= 2200 lbs dry solids/day removed to the digester.

In terms of a 6% liquid, digested sludge where the total solids reduction is 35% and the supernatant is decanted off we have:

$$2200 \text{ x } \frac{100}{6} \text{ x } \frac{1}{10} \text{ x } \frac{100 - 35}{100}$$

= 2400 gal/day to be hauled.

The above can be shown in the schematic below where the volatile solids content is 70% and that the volatile destruction is 50%.



In the case where the raw sludge is filtered we have (for a 20% solids content in the cake) :

2200 lbs dry solids x $\frac{100}{20}$

= 11,000 lbs of cake to be hauled.

In the case where the digested sludge is filtered we have (for a 20% solids content) :

2200 lbs dry solids x $\frac{65}{100}$ x $\frac{100}{20}$

= 7,150 lbs of cake to be hauled.

Dewatering

At present there are several methods available to dewater sludge. These methods include: (1) Drying Beds; (2) Vacuum Filtration; (3) Centrifuging; (4) Sludge Lagoons. It shall be noted that the above methods produces sludge cake which must be disposed.

(1) Drying Beds

One of the more simple and economical methods of dewatering sludge is the use of drying beds. Although not used extensively in Ontario, approximately 2/3 of the sewage treatment plants in the United States have them. Using this method, a sludge can be dried to approximately 25 per cent (%) or more dry solids during a period of several days of dry weather. The de-watered cake is usually loaded onto a truck by using a shovel or garden fork. The reason heavier, mechanical equipment is not used is because the underdrain system cannot withstand heavy loads on it. The surface area required for sludge drying beds is determined first by climatic conditions.

The basic principle in dewatering of sludge on sand drying beds is filtration of the water through the sand and surface evaporation. The filtration usually takes place during the first few days, but depends on the sludge characteristics and depth of sludge applied to the drying bed.

After the filtration stage is completed the sludge then dries to an equilibrium moisture content with the surrounding air. Therefore the drying does not only depend on temperature but on the relative humidity of the air and the nature of the water in the sludge. It should be noted that some water in certain types of sludge are bound for example: raw and partially digested, and therefore does not dewater easily. However digested sludge is easily dewatered because it contains a low bound water content.

Unless the sludge drying bed is properly constructed it is of little use. Sludge drying beds normally consist of approximately 5 inches of sand over approximately 10 inches of gravel. The bed is drained by the underdrains placed in gravel about 9 feet apart; this space will depend on sub-soil characteristics. The sub-natant from the underdrain system should be returned to the primary clarifier or aeration section of the treatment plant for further treatment. Sidewalls of the beds are made of concrete, wood or earth berms. The height of the sidewalls is usually 1 foot and the sludge is usually pumped to a level of 6 to 10 inches. It should be noted that several little beds are better from an operation point of view than one large single bed. The width of the bed is flexible; however, through practice it has been found that 20 feet is a good operational width. The length is usually less than 100 feet. Sludge may be expected to flow approximately 100 feet from a single outlet when the grade of the bed from the outlet is 5 feet per thousand feet.

Although sludge drying beds are not extensively used, usually in Ontario the ones which have been designed and operated properly have given satisfactory results.

(2) Vacuum Filtration

Vacuum filtration is one of the most widely used types of mechanical sludge dewatering devices. Filters are adaptable to handling the various forms of raw and digested sludge. The basic process of filtration is separation of the solids from the liquid by means of a porous media which retains the solids (filter cake) and lets the liquid portion pass through (filtrate). The filter media used are of four basic types: (1) Fabric Covered Filter (cotton, wool, felt, dacron, saran, polyethylene and others), (2) String Filters (These filters use a fabric media but the sludge cake is removed from the drum by strings which pass around it), (3) Travelling Belt Filters (These consist of a stainless steel woven wire belt which serves as filter media),

(4) Coil-spring Filters (Two layers of coiled steel springs are placed in a corduroy fashion around the drum. As the layers leave the drum, they are separated from each other and the filter cake is lifted off and discharged).

The filtration process is accomplished by means of a horizontal drum covered with a filter media. The drum is rotated in a tank with about one quarter of the drum submerged in wet sludge. Valves and appurtenances are arranged in such a manner that as the drum rotates, a vacuum is applied on the inner side of the filter media, drawing out water from the sludge and picking up a layer of sludge on the filter media. The vacuum is continued as the drum revolves and this continuous vacuum pulls the unbound water from the sludge mat, leaving a semi-dry cake of sludge on the outer surface. The sludge cake is then scraped, blown or lifted away from the drum before it enters the sludge tank again.

The performance of the vacuum filter is measured by the rate at which dry solids are produced (pounds per hour of dry solids filtered per square foot of filter surfacc). These rates will vary according to the type of filter media used and type of sludge dewatered.

The filtering rates for various sludges are indicated below:

Type of Sludge	Average Yield lb/sq ft/hr	Range
Primary	8	6.5-11.5
Primary digested	7	4.5-12.5
Primary digested-elutriated	7	3.2-13.0
Primary and Activated	4	
Primary digested and Activated	3	2.3-3.2
Primary digested and Activated elutriated	3.1	

Operating costs for vacuum filtration vary greatly from one installation to the next. However, when final disposal is incineration, then the vacuum filter can be used on non-digested sludges thereby eliminating the necessity of a digester and reducing the overall capital and operating cost for the treatment plant.

Prior to being dewatered, most sludges must be pre-conditioned or flocculated using chemicals. When flocculation occurs, the solid particles are agglomerated in the liquid and the liquid is withdrawn by vacuum while the solids are deposited on the filter media.

The chemicals used for flocculation vary; however, the most commonly used chemicals are polyelectrolyte (polymers), ferric chloride and lime. The amount and type of chemical used will depend on the sludge to be filtered. Several factors influence the chemical demand:

1. Sludge Concentration
2. Type of Sludge
3. Size, Shape, Density, and Charge of Solid Particle
4. Compressibility of Solid Particles
5. Viscosity of Filtrate
6. Chemical Composition (Alkalinity)

Sludge concentration is a critical factor. Increasing the solids concentration will increase the filter yield. The more concentrated the sludge, the less filtrate has to be removed per pound of filter cake deposited. Concentration also lessens the liquid demand, and, hence, lowers the amount of chemical coagulation required. Since activated sludge is thin (usually less than 1% total solids) the chemical demand for this type will be much higher than a concentrated primary sludge (6-10% total solids).

The second most important factor is alkalinity. If alkalinity is reduced, the chemical demands are reduced. One process which reduces alkalinity is *elutriation*.

Basically, elutriation is a solids washing process. An elutriated sludge is one that has had the alkalinity of its water reduced by dilution, sedimentation, and decantation in water of much lower alkalinity.

One important point that must be noted is that inconsistency of sludges. Sludge will not remain the same and no two sludges have the same characteristics. Therefore, if for some reason one particular type of chemical works well for your neighbour it will not necessarily work for you.

(3) Centrifuging

One of the more recently established methods of dewatering is centrifuging. There are several types of centrifuges available and all have their particular application.

A centrifuge is basically a clarifier with the sedimentation taking place under forces greater than gravity. The centrifugal force produced in the machine acts on a suspended particle in the sludge, causing it to settle through the liquid component. By either rotating the bowl at high speed or by the addition of chemicals the settling forces acting on the solid particles are increased greatly.

Several variables affect the theoretical clarifying capacity of centrifuges: 1. particle size, shape and maximum settling rate of the smallest particle to be handeled; 2. the time under which the centrifugal force is available for settling; 3. the liquid depth through which the solid particles must settle.

The foregoing gives the basic theory behind the operation of centrifuges. Although the number of installations in Canada is very limited, good operating data has been obtained.

The operation of a centriguge at Simcoe, Ontario determined that a good centrate, one which has a suspended

solids content of less than 200 mg/l, a disposal cake, some in the order of 16-25% plus or minus 5% could be obtained at an overall cost lower than the conventional methods of disposal. It also determined that manpower was not a factor.

(4) Sludge Lagoons

Another method of dewatering sludge is sludge lagoons. This method of dewatering was widely used in Europe; however, because of the large land requirements it has fallen in to disuse. The basic principles on which a lagoon operates is evaporation and supernatant withdrawal. Without both of these principles in operation the usefulness of lagoons is seriously limited.

During the last few years sludge lagoons have been in operation at the Kitchener WPCP in Ontario. Approximately ½ of their sludge production is directed to 20 acres of lagoons. There are three lagoons located at the project and one lagoon is filled yearly. It has been found through practice that operating levels should not exceed three feet if the sludge is to be dewatered. Certain periods of the year find the supernatant on the surface and in turn the supernatant is pumped to the primary clarifier of the plant. During the year when the third lagoon is being filled the first lagoon is emptied by drag line and dumptruck. To date this method of dewatering is very economical. However, the long term effects of the surrounding area have to be studied further.

HEATING, DRYING AND COMBUSTION

Wet Oxidation (Zimmerman Process)

The wet oxidation process is a method of incineration that uses the principle of wet combustion to degrade the organic matter in sludges. Oxygen is added to support the combustion. The sludge is reduced to an ash. The liquid portion of the effluent carries the ash to a tank or lagoon where it is then removed by sedimentation.

Wet oxidation can be used in the disposal of either raw or digested sludge. Vacuum filtering is not a necessary requirement, and an 80-85% reduction of BOD of the sludge can be achieved.

Although at present the Zimmerman process is not used in Ontario, during the next few years this process will be used to dispose of the sludge from the Lakeview Sewage Treatment Plant. One of the basic reasons that it is being used there is the solid residue produced which can be used in landfill. As everyone realizes, agricultural land is at a high premium around Toronto. In addition the quantities of sludge are so vast that liquid or cake haulage is not practical.

Heat Drying

Heat drying is one process that is not used often although there are installations in the United States. It has been used in the manufacture of soil conditioners. This method of volume reduction can be used on most types of sludges--primary, secondary, raw or digested.

Drying of sludge is accomplished for the following reasons:

1. To reduce the volume of sludge by lowering the moisture content from 75 per cent to 10 per cent.

2. To retain the fertilizing properties of the sludge.

3. To retain and improve its soil conditioning properties.

4. To destroy organisms capable of producing disease.

5. To reduce odours in the sludge.

Drying of the dewatered sludge may be performed by the following equipment:

1. rotary kiln dryer--this is a cylinder set on an inclined plane with length eight to ten times its diameter.

The cylinder revolves at a very slow speed (4 to 8 rpm). The sludge to be dried enters at the upper end and is carried to the discharge by gravity as the cylinder rotates . Heated gases (up to 700°F) are introduced to the cylinder and mixed with the relatively cold sludge. The exhaust gases from the drier must be oxidized at a temperature of 1200 to 1400°F in order to reduce serious air pollution.

2. flash dryer--consists of a cage-type mill where the sludge particles are dried almost instantly as they are removed and held in suspension in a stream of hot gasses (1100°F). The gas-borne sludge particles are blown to a separator where the dried sludge is trapped and removed from the moisture-laden gases.

3. spray drier--consists of a vertical tower down which a current of hot gases flow. Fine particles of wet sludge are sprayed into the tower and the water evaporates from the sludge particles and passes off with the gases into the atmosphere. Dried sludge from the rotary kiln is granular and may contain larger clinker-like masses which require grinding. The waste resulting from the flash and spray driers is a fluffy material suitable for fertilizer use.

Sludge Composting

The composting of sewage sludge and municipal garbage into humus valuable as a soil conditioner and nutrient for plants is the alternative to landfill or incineration. However, the method is based on the recycling of wastes back to the soil and is therefore strongly dependent on the demand for the compost product.

Composting may be defined as the biological decomposition of organic solid wastes to a relatively stable end product.

The first process that the garbage would undergo would be that of salvaging useful materials and separation of undesirable debris. Approximately 35% of normal

municipal refuse cannot be composted and should be removed at this or subsequent stages. Salvage of ferrous metals could be by magnetic separator, or by hand picking from conveyor belts.

The next process for the garbage would be grinding, which reduces the garbage to a maximum particle size which is desirable to promote uniform aeration and moisture distribution in the material during aerobic decomposition.

At this stage the garbage could be subjected to a further salvaging and debris separation process.

The next step in the composting process is that of mixing the garbage with the sewage sludge. The purpose is to form a homogenous mixture with a uniform moisture content of 60 to 65%. Less moisture would retard the subsequent aerobic decomposition process whereas more would promote undesirable anaerobic decomposition. The ratio in which the sludge and garbage is mixed depends on the moisture content of the sludge and to a lesser extent on that of the garbage. The degree to which the garbage has been processed prior to mixing also invluences the amount of sludge that can be used.

From the standpoint of promoting the aerobic decomposition of the garbage-sludge mixture and increasing the quality of the end product of the overall composting process, it is preferable that raw sludge be used. Raw sludge has a greater nutrient concentration than digested sludge, and these nutrients are needed to speed up the decomposition of the garbage. However, as greater volumes of raw sludge than digested will be generated, the use of raw sludge may necessitate dewatering if all of a community's sludge is to be used for composting.

After mixing and moisture adjustment the gargage-sludge mixture goes to an aerobic digestion process. After aerobic decomposition, the necessity for further processing will depend on the use to which the compost product is to be put. For use on agricultural land, probably no further

processing would be required. For use in market gardens or nurseries, screening with regrinding of oversize particles could be used.

Final Disposal

(1) Incineration

Incineration is a popular method of sludge disposal at very large sewage plants. It has the advantage of freedom of any odours, independence of weather and in the volume and weight of the end-product to be disposed of. There is a minimum size of treatment plant below which incineration is not considered economical since the process requires the use of expensive equipment.

Incineration of sludge is accomplished for the following reasons:

1. to destroy all organic material;
2. to kill all organisms;
3. to control by burning all the gases released;
4. to reduce the volume to a minimum;
5. to produce a readily disposable material by the most economic means of disposal.

Incineration is achieved by flash type incinerators, which are similar to the flash type driers but at a temperature of approximately 1600°F, and multiple-hearth furnaces where the sludge is burned to an ash.

The multiple-hearth furnace consists of a vertical cylinder containing a series of four or more hearths, one above the other. Partially dewatered sludge cake is fed to the upper hearth and dried by the hot gases from the lower hearths. This partially dried sludge is moved successively down to the next lower hearth mechanically until dried to a point where it will ignite and burn. Because incinerators have smoke stacks, air pollution control devices have to be included to prevent the discharge of odours, dust, fly ash and soot. The ash is usually transported to a landfill site for disposal.

(2) Disposal at Sea

Although this method of disposal is not generally practiced in Canada, several coastal cities in the United States, for example, Los Angeles, dispose of their waste sludge and incineration ashes in the sea. A number of large cities barge sludge 15 to 30 miles at sea and discharge them in the ocean. The areas used for dumping are designated by the appropriate level of Government. Although it has been assumed that the assimilation by oceans was infinite, at present certain warning signs have been given by the oceans and the method may have to be stopped or curtailed.

(3) Land Disposal by Liquid Haulage

This is the most common method used in smaller communities in Ontario. Because of the great use of this method certain guidelines for sludge disposal (a copy of which is appended to this section) were drawn up by the Project Operations Branch of this Ministry.

(4) Tank Truck Haulage

Many municipalities are using this method of sludge disposal. It is popular where residences are located close to the plant or space is limited for lagoons or sand beds. It is a simple and economic procedure if the distance to the dump site is not too great.

NOTE: Both raw and digested sludges may be spread on land where adequate aging and cultivation is affected. Where an adequate aging period is not allowed the land should not be used for crops which may be eaten raw. *At no time should either raw or digested sludge be spread on growing crops which may be consumed raw.* Unless sludges are effectively heat dried they should not be spread on active grazing land. Forage crops which have been treated with sludges not rendered innocuous by heat drying should be cured before use.

With the exception of the nitrogen and phosphorous content in undigested activated sludge, the fertilizer content in sludge is small. Therefore, the greatest percentage of sludge products are classified as soil *conditioners*, and not fertilizers. Nevertheless, this material whether termed as fertilizer or soil conditioner, can provide valuable humus and trace elements to the soil. The three main constituents required in commercial fertilizer are nitrogen, phosphorous and potassium. Nitrogen and phosphorous are available in good percentage in sewage sludge while potassium is generally available in amounts less than 1 per cent.

The type of sludge treatment as well as the nature of the raw sewage have a great bearing on the value of the resultant sludge as a soil conditioner. With respect to nitrogen content, undigested activated sludge is greatest, with digested activated sludge, raw primary sludge, and digested primary sludge following in that order.

In purchasing a vehicle, the quantity of sludge to be removed must be known as well as the length of haul, the time an operator is available, and other uses for which the truck may be used. For small plants, finances will greatly limit the type of vehicle which may be obtained.

Sludge tanks used for liquid sludge transportation should be constructed with an oval or round cross-section. Structural cracks will develop in the thin plate if a square design is followed. The use of twelve gauge high tensile steel plate will provide corrosion resistance and more than adequate strength. For the sludge discharge line the use of a top operated valve, located in the tank itself, will prevent freezing during winter operation. When a four inch gate valve is used, the pipe between the tank and the valve itself must be insulated and also provided with a heating element. The tank must also be constructed with adequate internal baffles, inspection and loading manholes, and vacuum relief valves on the top.

Sludge cake should be handled in a dump box equipped with a water tight gasket on the rear gate. The sides should have more than normal freeboard allowing one cubic yard of volume for each ton of cake to be carried. A heavy duty hoist is recommended to enable spreading with the box up while travelling over rough terrain.

When disposing of sludge, great care must be taken to ensure that nuisances are not created. Common sense rules must be followed to prevent obnoxious odour complaints. When a municipality receives numerous complaints regarding refuse and sludge disposal, very restrictive regulations may be enacted.

Only very isolated dumping areas should be used for raw sludge and the applied material must be plowed in very quickly. Winter weather will prevent odours but it may be difficult to work the sludge into the soil early in the spring and obnoxious odours might develop at that time. In general, raw sludge products must be handled very carefully. It might be advisable to dispose of raw sludge at a landfill project, where daily coverage can be provided.

Digested sludge is less odourous and therefore immediate coverage is not as important. Liquid sludge can be spread evenly and thinly. Where quick drying is possible, on sandy and elevated dry land, it may be disposed of close to homes. Nevertheless, great care must be taken that obnoxious odours do not carry to residences and furthermore, only well digested liquid sludge can be considered in this category.

Digested sludge cake must be handled more carefully. It is difficult to spread thin and therefore wet lumps of material may emit some offensive odours. If possible this material should be worked into the soil soon after spreading.

SUMMARY

(1) It is desirable to thicken the sludge prior to sand bed drying because there is less water to be removed and, therefore, an accompanying decreased drying time is required.

(2) Vacuum filtration and heat drying are independent of weather conditions. However, they require considerable labour and are very expensive.

(3) Tank truck disposal is final and cheap. But a moderate labour force is required which is significant in the holiday season.

(4) Drying beds fall midway between other methods in total cost and labour requirements are low. However, disposal of the dried sludge could be difficult and the large area required is their greatest disadvantage.

INTERIM GUIDELINES FOR DISPOSAL OF SLUDGE BY LAND APPLICATION

NOTE

a) The following pertains to the disposal of sludge which had undergone proper anaerobic or aerobic digestion or other suitable processing, at a municipal sewage treatment plant.

b) It is intended that the method of land application entail the utilization of sludge in the agricultural industry, as opposed to merely disposing of the material.

1. Site Location

1.1 The site should be remote from surface water courses. The minimum distance between the site and the surface water course should be determined by the land slope as follows:

Max. Sustained Slope	Minimum Distance to Watercourse For Sludge Application During May to Nov. inclusive	For Sludge Application During Dec.to Apr.inclusive
0 to 3%	200 ft.	600 ft.
3 to 6%	400 ft.	600 ft.
6 to 9%	600 ft.	No sludge to be applied
greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

1.2 The site shall be at least 300 ft. from individual human habitations.

1.3 The site shall be at least 300 ft. from water wells.

1.4 The site shall be at least 1,500 ft. from areas of residential development.

2. Land Characteristics

2.1 The land slope and soil permeability will determine the time of year that sludge may be applied, as follows:

Max. Sustained Slope	Soil Permeability**	Allowable Duration of Application: Southern Ont.	Allowable Duration of Application: Northern Ont.
0 to 3%	any	12 mon/yr.	12 mon/yr.
3 to 6%	rapid to moderately rapid	12 mon/yr.	12 mon/yr.
	moderate to slow	10 mon/yr. (May to Feb.)	9 mon/yr. (June to Feb.)
6 to 9%	rapid to moderately rapid	7 mon/yr. (May to Nov.)	6 mon/yr. (June to Nov.)
	moderate to slow	6 mon/yr. (May to Oct.)	5 mon/yr. (June to Oct.)
greater than 9%	any	No sludge application unless warranted by special conditions	

** Soil permeability classification shall be in accordance with Tables 1 and 2 of the Ministry of Agriculture & Food's publication entitled "Drainage Guide for Ontario" (See Apendix 1). The type of soil should be determined with the use of County Soil Maps available through the Ministry of Agriculture & Food.

2.2 The ground water table during sludge application should be not less than 3.0 ft. from the surface for soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability the ground water table should be not less than 5.0 ft. from the surface.

2.3 Where sludge application is carried out by tank truck, untilled land should be given preference to tilled land. Where tilled land is used the sludge hauling contractor should request instructions from the landowner, with regards to minimizing the possibility of damage to the tile system.

3. Site Management

3.1 When sludge is applied to agricultural land, the land is to be used only for pasture, fallow or the growing of forage crops. Dairy cattle should be excluded from pasture land. These restrictions on land use shall apply from the date of application until the end of the calendar year during which the sludge has been applied.

3.2 The boundaries of the site shall be marked (eg. with stakes at corners) so as to avoid confusion regarding the location of the site during sludge application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

3.3 Soil tillage and sludge application should where possible follow the contours of the land (to maintain a contour furrow system). Passage of sludge spreading vehicles over the land should be minimized, to reduce compaction of the soil (eg. the allowable sludge application rate in cu. yds./A/yr., could be achieved after one or two passes).

3.4 Special precautions may be required where the possibility of localized surface water runoff problems exist.

4. <u>Sludge Application Rates</u>

4.1 In determining the allowable rate of sludge application for a particular parcel of land, the objective shall be to match as closely as possible the quantity of nutrients removed from the soil by the harvesting of the crop. The allowable rate will thus be determined by the nutrient content of the particular sludge and the nutrient uptake capabilities of the particular crop under consideration.

The sludge hauling contractor shall adhere to the application rate (in cu. yd./A/yr.) specified in the Certificate of Approval issued by the Waste Management Branch of the Ministry of the Environment. The suitability of sludge application rates may if required be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Waste Management Branch.

4.2 The sludge shall be spread uniformly over the surface of the land.

4.3 The sewage treatment operating agency is to keep records of the location of all the sites used for the disposal of its sludge and the sludge quantities disposed of at each site, each week (eg. volume of sludge in cu. yds., and weight of sludge solids in tons). The operating agency shall ensure that at least every 3 months, samples of the sludge are submitted for thorough analysis (eg. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, ether extractables, heavy metals, etc.).

APPENDIX I

Note: The following tables are extracts from the Ministry of Agriculture & Food's publication No. 29 entitled "Drainage Guide for Ontario".

Table I - Drainage Key for Soil Groups

Soil Group	Permeability	Slope	Typical Soil Type
1a	Slow	Level to depressional	Jeddo
1b		Level to undulating	Haldimand
1c		Undulating	Caistor
2a	Moderate	Level to depressional	Brookston
2b		Level to undulating	Brookston
2c		Undulating to rolling	Perth
3a	Moderately rapid	Level to depressional	Parkhill
3b		Level to undulating	London
3c		Undulating to rolling	Guelph
4a	Rapid	Level to depressional	Granby
4b		Level to depressional*	Wauseon
4c		Level to undulating	Brady
4d		Level to undulating*	Berrien
4e		Undulating to rolling	Fox
5		Bedrock at less than 2 feet	Farmington
6		Organic Soils	Muck, Peat

* Clay at 6 feet or less

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 8

PROBLEMS CAUSED BY

INDUSTRIAL WASTE

OBJECTIVES:

Trainee will be able to:

1. Name 8 standards that should be incorporated in a sewer use bylaw.
2. List 7 causes of problems at the *treatment plant* due to industrial wastes.
3. List 6 possible causes of problems in *sewers* due to industrial wastes.

PROBLEMS CAUSED BY INDUSTRIAL WASTES IN SEWERS AND SEWAGE PLANTS

General

Most sewage treatment plants have experienced the problems that can be caused by industrial wastes. In fact, life would be very simple if it were not for the occasional slugs of grease that send personnel scurrying for skimming buckets. Plant operation is easy under ideal operating conditions, but foresight and ingenuity are required to prevent problems, such as those resulting from industrial wastes, without upsetting the entire plant.

Sewer-Use By-Law

Usually a municipality enacts a sewer-use by-law to control the quality of the waste flows being discharged to the sanitary system. If the industries comply with this by-law, there should be no problems in the sewers or at the plant. The important features of such a by-law are that discharges must comply with the following standards:

1. temperature - not greater than $150^{\circ}F$
2. pH - between 5.5 and 9.5
3. organic loading as measured by the 5-day biochemical oxygen demand (BOD_5) - not greater than 300 milligrams per litre (higher in large municipalities)
4. suspended solids - not greater than 350 mg/l (higher in large municipalities)
5. toxic materials should not exceed the following levels:

cyanide as HCN	2 - 5 mg/l
phenols	0.1 - 1.0 mg/l
sulphides as H_2S	2 - 5 mg/l
metals	3 - 10 mg/l

6. oils and greases or those substances soluble in ether
   (a) of mineral origin - not greater than 15 mg/l
   (b) of animal or vegetable origin - not greater than 100 mg/l
7. there must be insignificant amounts of explosive, inflammable and/or radioactive materials present
8. flow volumes must not result in hydraulic overloading of the system

<u>NOTE:</u> *Where a range is given, the higher levels would apply to the large municipality.*

The effect of any one industrial discharge on the entire sewage flow will depend on their relative volumes. As most industrial wastes can be treated with domestic sewage in municipal treatment plants, it may be possible for a municipality to accept and treat wastes that do not comply with the by-law limits without upsetting the operation of the sewage treatment plant. The municipality may wish to supply this additional service at no extra charge, or they may require a special agreement with the industry and additional money for this service. Normally, there is a section in the by-law that provides for this agreement. In order that the municipality may decide how to handle any particular situation, they must know the probable effect of any waste flow on their sewers and sewage treatment plant.

An Industrial Point of View

An industry views the treatment and disposal of its wastes as a matter of economics. It expects and deserves treatment of flows within the by-law limits for the normal sewer rate charge. If the municipality will accept a higher strength waste for a sum less than that

needed to pretreat the wastes to by-law limits, it is good business for the industry to use this method of disposal. Many times, the full strength waste cannot be treated at the municipal plant. It is then up to the industry to pretreat to a level which is acceptable to the municipality. It is quite often easier to remove contaminants from a waste flow at the source within the industry, and this should be done where possible.

Possible Problems

The problems that may be anticipated in *sewers* from flows not in compliance with sewer-use by-laws may be outlined under the following headings:

1. Flows - Excessively fluctuating flows may overload the hydraulic capacity of a sewer and cause backing up of sewage into basements, or overflowing at pumping stations.

2. Temperature - The higher the temperature of a waste discharge, the greater the biological activity in the sewer (rate doubles for every $10^{\circ}C$ rise). Thus the oxygen supply is quickly depleted and septic conditions occur. Also, high temperatures speed up corrosion and place thermal stresses on the sewer pipes and joints.

3. Suspended Solids - May settle in the sewers and cause blockage.

4. pH - Variance beyond the acceptable limits will result in corrosion of the sewer.

5. Oils and greases will build up on the inside of the lines and reduce the sewer capacity.

6. Dissolved Salts - Certain dissolved salts may precipitate out in the sewers and lead to blockages and/or corroding conditions.

More important, however, is the effect of industrial waste discharges on the operation of the *sewage treatment plant*. First the symptoms must be recognized; then the type and extent of the problem diagnosed and the effect it will have, or has had, on the various processes must be assessed. Finally, and most important, quick remedial action must be taken to offset the changing conditions. Following are comments on characteristics of industrial waste discharges of concern to a sewage plant operator, and relating to the detection and effect on the (a) primary section, (b) biological processes, as well as the corrective action to be taken.

1. <u>Flow</u> - excessive or surging flow conditions may be noted on the flow measuring devices within the plant or simply by noting the level of the flow on the walls of the channels. High flow rates tend to flush the tanks out, thus affecting the detention times and the treatment provided. Little can be done to ease this condition at the sewage plant; it should be corrected at the industry where the flows may be equalized.

2. <u>Temperature</u> - the rate of biological activity increases with temperature in a waste flow and the resulting septic conditions may be noted by the smell and low dissolved oxygen content of the raw sewage at the plant. A septic sewage will cause septicity in the primary clarifiers and exert an increased oxygen demand in the secondary biological section. The action required in this case would be to pre-aerate or pre-chlorinate the raw sewage flow.

3. pH - a waste with a pH value outside of the accepted range (5.5 - 9.5), besides creating corrosive problems throughout the plant, will tend to reduce the settling and biological processes. This condition may be noted by checking the waste flow with pH paper at regular intervals. Again, little can be done at the plant. The situation should be corrected by having the industry neutralize its wastes before discharge.

4. Organic loading (biochemical oxygen demand - BOD) - high strength industrial discharges will show up in the 5-day BOD test, but this does not help the operating personnel concerned with operating conditions at any given moment. These high strength wastes can usually be spotted by an *unusual colour* (eg. red; indicating blood, dye, etc.), *smell* (eg. a putrid smell because of the rapid depletion of oxygen in the sewer lines) or the inclusion of tell-tale *solids* (feathers, hair, etc.). If the high strength is due mainly to dissolved components, it will have little effect on the primary treatment process but will create a high oxygen demand and extreme sludge growth in the secondary biological section. If a significant amount of suspended material is included in the high strength waste, additional quantities of sludge will accumulate in the primary tanks and the digesters may be taxed beyond capacity. The action that should be taken at the plant would include carrying a higher concentration of solids and air in the aeration section and the possible addition of alkaline materials to the digesters as well as additional hauling of digested sludge so that a correct environment may be maintained for the anaerobic decomposition process.

5. Suspended Solids - this characteristic of the waste flow is one of the most recognizable and usually a

close examination with the naked eye will reveal unusual conditions which should be taken into account. The majority of the particles in suspension should settle out in the primary settling tanks. While most will be controllable by anaerobic treatment, some particles such as clay, chicken beaks, hair and bark will decompose very slowly, using additional digester capacity. Adjustment in digester operation as well as cleaning of the digesters may be required if these solids are allowed to get through the preliminary screening devices.

6. Toxic materials - toxic materials such as copper, chromium, phenols, etc. may be difficult to detect in the raw sewage if they are present in low concentrations. Should either the aerobic or anaerobic biological section be upset, however, laboratory analysis is required to confirm any suspicion in this regard. Higher solids could be carried in the aeration section to help in preventing an upset.

7. Oils and greases - these ether soluble materials will usually come to the surface in the grit tanks and primary clarifiers, making their presence obvious. If they can be skimmed, either by means of the regular skimming facilities or manually, these materials should be of little concern.

NOTE: *In most cases, sophisticated laboratory equipment is not a necessary part of good sewage plant operation. More important is the ability of the operator to adapt his thinking to the situation at hand and to take proper remedial action.*

Resourceful plant personnel will not only provide good plant operation, but will also note the time and conditions of any upsets at the plant. An attempt should be made to determine the section of the sewer system from which the upsetting discharge came and to define as closely as possible the problem industry. Armed with this information, the municipal officials, after investigating conditions at the industries in the area, should be able to locate the culprit and thus be in a position to enforce their sewer-use by-law.

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 9

CHLORINATION OF SEWAGE

OBJECTIVES:

Trainee will be able to:

1. Name the seven (7) physical properties of chlorine.

2. Explain the main purpose for chlorination of sewage treatment plant effluents.

3. Name and explain four other uses of chlorine in sewage treatment plant operation.

4. Define:
   - chlorine dosage
   - chlorine demand
   - chlorine residual

   Explain how they relate to each other.

5. Using mathematics, calculate the dosages of chlorine required to obtain the chlorine residual in the plant effluent.

6. List three methods used to determine chlorine residual.

CHLORINATION OF SEWAGE

Introduction

Chlorination means application of *chlorine*. The principal purpose of chlorination is *disinfection* of plant effluent--killing bacteria and viruses harmful to man. In the killing of the bacteria and viruses the chlorine does not do it directly but mainly by the formation of hypochlorous acid (free residual chlorination) which is formed when chlorine gas and water are mixed in the chlorinator and injected into the chlorine contact chamber. Chlorine is also used for:

(1) the control of odours,
(2) the reduction of BOD,
(3) aiding the activated sludge process,
(4) other purposes in sewage treatment

Chlorine may be applied as a gas, as a gas dissolved in water, or in the form of a hypochlorite obtained from salts such as sodium or calcium hypochlorite which, when dissolved in water, release chlorine. Chlorine gas costs much less, is not as bulky as the hypochlorite form, and is generally used in sewage treatment, unless a relatively small quantity of chlorine is required.

Table 9-1 Chlorine Properties

Greenish-Yellow colour gas (poisonous)
2½ time Heavier than Air
Amber Colour Liquid (when compressed)
High Rate of Expansion
Moderately Soluble in Water
Non-Flammable and Non-Explosive
Supports Combustion at High Temperature

Chlorine is a *poisonous* greenish-yellow gas with a penetrating characteristic odour at normal temperature and pressure. It is 2½ times as heavy as air, and one volume of liquid chlorine equals 450 volumes of chlorine gas. It can be compressed into a liquid which has a clear amber colour. At $-29^{\circ}F$ chlorine has zero (0) vapour pressure, and at room temperature of ($68^{\circ}F$) its vapour pressure is 82 pounds per square inch. Chlorine has a high co-efficient of expansion. For example a temperature rise of $50^{\circ}F$ (say $20^{\circ}F$ to $70^{\circ}F$) will increase the liquid volume from 84% to 89% in the cylinder. Such an expansion could easily rupture a cylinder or the feed line full of liquid chlorine. This is the reason for the regulation that chlorine containers must not be filled to more than 85% of their volume, and also this has to be considered when:

(1) feeding chlorine gas from a cylinder
(2) dealing with a leaking cylinder

Note (For detailed procedures outlining the handling of chlorine gas cylinders refer to *"Topic 4"* in the Ontario Ministry of the Environment *"Basic Gas Chlorination Workshop Manual".)*

Chlorine by itself is non-flammable and non-explosive but it will support combustion.

Physiological Effects

Chlorine can be detected by smell, even in very small concentrations. *The least detectable amount of chlorine in the atmosphere is about 3.5 (mg/l) and when this occurs, the operator should be alerted to potential hazards, such as leaks, or faulty equipment.* At higher concentrations, chlorine will have physiological effects. The maximum amount that can be inhaled for one hour without serious effects is about four (4) mg/l. At fifteen (15) mg/l, chlorine will cause irritation of the throat; at thirty (30) mg/l, it will cause serious spells; and at forty (40) to sixty (60) mg/l, it is extremely dangerous for one half-hour exposure. A few breaths of air containing 1,000 mg/l would be lethal.

Chlorine Dosage

The dosage of chlorine or any chemical indicates the amount being applied. It is measured as a concentration, such as the weight of chlorine applied to a certain amount of water or sewage, usually in milligrams per litre (mg/l) or parts per million (ppm). Example: if a chlorinator is set to feed 45 lbs of chlorine per 24 hours and the sewage flow is at a rate of 0.60 MIGD, the chlorine dosage would be calculated as follows:

$$\frac{45 \text{ lbs}}{0.60 \text{ MIG}} = \frac{75 \text{ lbs}}{1.0 \text{ MIG}}$$

$$= \frac{75 \text{ lbs}}{1.0 \text{ MIG}} \times \frac{1 \text{ gal}}{10 \text{ lbs}}$$

(1 imp. gal. water = 10 lbs.)

$$= 7.5 \text{ ppm}$$

$$\text{OR} = 7.5 \text{ mg/l}$$

Therefore the chlorine dosage would be 7.5 mg/l with the feed rate and the flow in the example.

Reaction of Chlorine in Sewage

To determine at what points as well as how much chlorine should be applied to the treatment process, the action of chlorine when added to sewage must be understood.

Chlorine is an extremely active chemical that will react with many compounds to produce many different products.

(a) If a small amount of chlorine is added to sewage it will react rapidly with such substances as hydrogen sulphide and ferrous iron. Under these conditions no disinfection will result.

(b) If enough chlorine is added to react with all of these substances (called reducing compounds) then a little more chlorine added will react with organic matter present and form chloro-organic compounds, which will have a slight disinfecting action.

(c) If enough chlorine is added to react with all of the reducing compounds and all the organic matter, then a little more chlorine added will react with ammonia and other nitrogenous compounds to produce *chloramines* or other combined forms of chlorine, which will *disinfect the sewage.*

The quantity of both organic and inorganic substances in sewage varies from place to place and from time to time, so the amount of chlorine to be added will also vary. The chlorine used by these organic and inorganic reducing substances is known as the *chlorine demand.* It is equal to the amount added minus that remaining as combined chlorine after a period of time, usually 15 minutes. *Disinfection results from that amount remaining after the chlorine demand has been satisfied.* The quantity of chlorine in excess of the chlorine demand is defined as the *chlorine residual.*

For example: if the chlorine residual was measured to be 0.6 mg/l then the chlorine demand could be estimated:

chlorine dosage	7.5 mg/l
chlorine residual	-0.6 mg/l
chlorine demand	6.9 mg/l

Purposes of Chlorination

Chlorination may be performed at a sewage treatment plant for many purposes but the most important is disinfection of plant effluent.

1. Disinfection

When sewage or treated effluents are discharged to bodies of water used as a source of public water supply or for recreational purposes, treatment for the destruction of pathogenic organisms is required to minimize the health hazards of these waters. Such treatment is known as disinfection.

To disinfect the plant effluent, sufficient chlorine must be added to satisfy the chlorine demand and leave a *chlorine residual* that will destroy bacteria. The amount of chlorine necessary to obtain a satisfactory reduction of bacteria will vary greatly with the degree of treatment the sewage has received. Disinfection of sewage has arbitrarily been defined as the addition of sufficient chlorine so that a chlorine residual of *0.5 mg/l* is available for at least a *contact time* of 15 minutes. This has been found to give adequate disinfection. *The ministry of the Environment expects this to be maintained at all times.*

Chlorine is a surface-active agent and there is a reasonable chance that bacteria hidden within solid particles will not be killed by chlorine. For this reason, chlorine is added for disinfection purposes at a point *after* solids removal. Because of possible hidden bacteria within particles, chlorination cannot properly disinfect raw sewage.

Control of Chlorination

As mentioned, a chlorine residual of 0.5 mg/l after 15 minutes of contact is required. To ensure at least 15 minutes of contact before discharging the effluent to a receiving stream a chlorine *contact chamber* is provided. The chamber is baffled to provide total mixing of chlorine with the effluent and prevent "short circuiting."

Accurate control of the chlorine residual may be impossible, due to the great variations in flow and strength of sewage. In small plants the residual should be checked each day when the maximum flow enters the plant. This normally ensures a sufficient chlorine dosage during the rest of the day. In larger plants the dosage should be adjusted during the night when the flow and chlorine demand is much lighter.

The operator should record all chlorine residual measurements and the amount of chlorine used each day. A comparison of the dosages and residuals can then be made. Also, there will be evidence that proper disinfection of the plant effluent is being performed continuously by the operating staff.

OTHER USES OF CHLORINE

There are numerous other uses of chlorination at a sewage treatment plant. However, difficulty arises since most plants, unless they are very large, are not equipped to apply chlorine at the many different locations as may be required. One should be aware of the possible uses since most are effective in correcting problem situations.

Odour Control

Odours in sewage treatment plants that are due to an anaerobic condition will usually respond to chlorination. In most cases the problem is to find the best point of application for the chlorine. In the case of primary clarifiers where the sewage has become anaerobic during the sedimentation period, the chlorine should be added to the incoming sewage. When the odour develops in the sewers due to a low velocity, the chlorine should be added far enough up the sewer so that it has adequate time to control the anaerobic condition before the sewage leaves the sewer.

Industrial wastes with high oxygen demand such as come from packing houses, canneries, milk plants, etc. will turn anaerobic very rapidly and if this type of waste is found to be causing odours it should be chlorinated before it enters the sewer.

In controlling odours it is not necessary to chlorinate to a residual. It has been found that a dosage of 40 - 60 per cent of the chlorine demand will give satisfactory control.

Aid to Sedimentation

Chlorination of raw sewage will improve the rate of settling in primary clarifiers. This is especially true when the sewage is anaerobic as it destroys the gas forming organisms and prevents the sludge from rising.

BOD Removal

Chlorine reduces the BOD of sewage in two ways. Some of the decomposable matter is oxidized by the chlorine resulting in a permanent BOD removal. Other compounds combine with the chlorine to form chloro compounds, some of which are toxic to bacteria and others are no longer broken down by bacteria. The BOD reduction will vary from 15 - 35 per cent depending on the condition of the sewage. Generally speaking the lowest reduction is obtained in fresh sewage and the highest in anaerobic sewage. A BOD reduction of 2 ppm for 1 ppm of chlorine is obtained up to the point where a chlorine residual is obtained. Beyond this point the rate of oxidation drops off.

Grease Removal

Chlorination can be used ahead of a clarifier as an aid in grease removal. The chlorine will break the grease emulsions allowing the grease to collect in larger particles that are easier to remove by skimming.

Activated Sludge

There are a number of ways that chlorine can be used to advantage in operating an activated sludge plant. In some cases sludge bulking can be controlled by chlorinating the return sludge. This will require about 5 ppm of chlorine and should be continued until a satisfactory sludge index is obtained. Sometimes at the start of this treatment the effluent becomes quite turbid but this condition should clear within a day.

When waste sludge that is being returned to the primary clarifier tends to float, chlorination of this sludge will give better settling.

When an activated sludge plant is overloaded there are several points in the plant where chlorine can be added to reduce the load. It can be used ahead of the primary clarifier to reduce BOD and increase the amount of solids settled, or it can be added to the aeration

channels to aid in oxidation. When added to the final clarifier, it can be used to control biological activity and prevent flotation of the sludge. The best point to add the chlorine can only be determined by experience and varies from plant to plant.

When a plant has become anaerobic from breakdown or overloading, chlorination is the quickest way to return it to an aerobic condition. In this case, chloride of lime is more effective than chlorine gas, as the pH is always low when a plant is anaerobic, and the lime raises the pH while the chlorine corrects the anaerobic condition. Care should be taken that the pH is not raised to the point where calcium carbonate is precipitated as it tends to form scale on the diffusers and plug them.

Supernatant liquor from digesters may cause a high oxygen demand on the activated sludge process that can be relieved by chlorination. Due to the high chlorine demand of this liquor, dosages as high as 80 ppm or more may be necessary to give adequate control.

Some success has also been attained in cleaning air diffusers by feeding chlorine gas into the diffuser headers.

Sludge Thickening

In some plants, sludges, both activated or primary, are thickened before they are pumped to the digester or dewatered. Chlorine can be used here to control bacterial action and better settling and concentration is obtained. To do this it is necessary to maintain a residual of 1 ppm of chlorine in the supernatant liquor above the sludge.

Breakdown of Concrete and Mortar

The hydrogen sulphide that develops in anaerobic sewage can cause other problems besides odour. This gas is quite soluble in water and will dissolve in moisture that has condensed on the walls and roof of a sewer. It is then oxidized by the air in the sewer to sulphuric

acid and will dissolve the cement from the concrete and mortar and allow them to crumble. Chlorine, of course, is the answer to this problem, as it will oxidize the hydrogen sulphide before it condenses on the surface of the concrete and will also control the organisms that produce the gas.

Testing for Chlorine Residual

There are three methods used in testing for chlorine residual:

(1) orthotolidine test
(2) D.P.D. test (Diethyl Phenylene Diamine)
(3) amperometric titration test

Orthotolidine Test

The OT method is an old one dating back to 1914, and is still in use in many plants. It is reasonably good for determining total chlorine residual but the Free chlorine residual result obtained by this method is only an approximate one.

D.P.D. Test

Research studies in chlorine chemistry have resulted in the development of a very simple procedure for the determination of residual chlorine compounds in water. Free or combined chlorine residual can be analyzed by this method. Differentiation and accurate determinations of these various forms of chlorine residual simplify the control of modern chlorination processes.

Amperometric Titration Test

The most accurate method of measuring free and combined chlorine residuals is by the oxidation-reduction titration procedure. This method requires the use of an electronic device called the Amperometric Titrator.

These methods of measuring chlorine residual are described in detail in the Basic Gas Chlorination Workshop Manual (1973).

SUBJECT: TOPIC: 10

BASIC SEWAGE TREATMENT OPERATION

RECORDS & LAB TESTS

OBJECTIVES:

Trainee will be able to:

1. Explain the purpose of sampling.

2. Describe in general terms the following lab tests:

   - BOD
   - suspended solids
   - mixed liquor suspended solids
   - settleable solids
   - dry solids
   - volatile solids

3. Discuss the importance of each of the above tests.

4. Explain the importance of comprehensive and up-to-date record keeping.

RECORDS AND LABORATORY TESTS

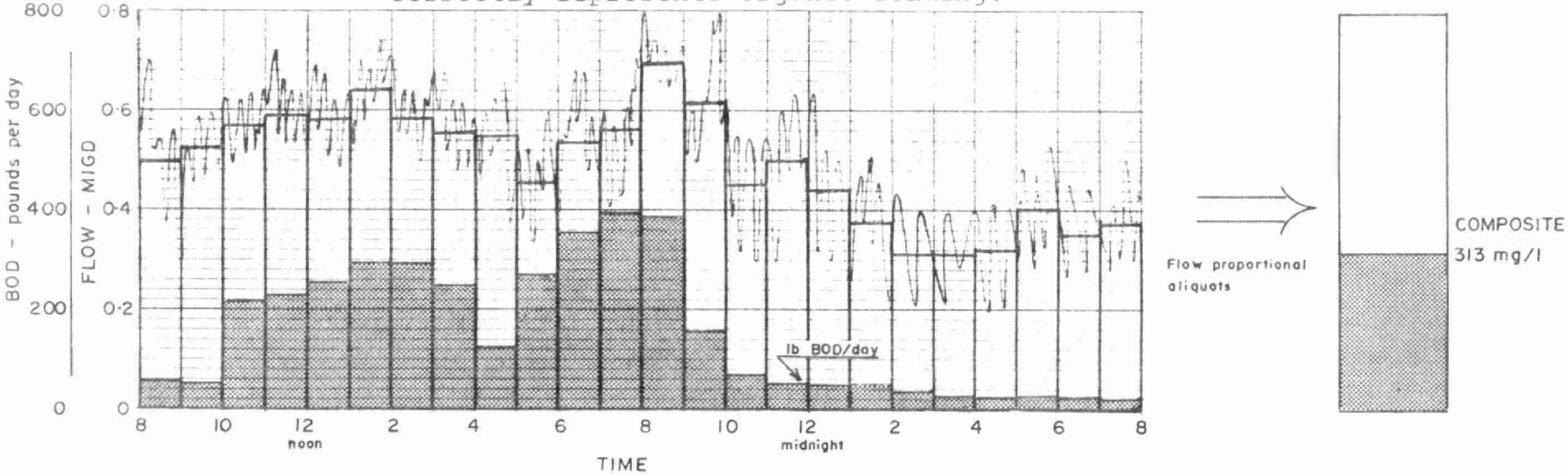
INTRODUCTION

Sewage is treated to produce an effluent which will not impair the quality of the environment. If spending money is necessary to reduce pollution, then a knowledge of plant performance is necessary to justify the cost and to assess the treatment. A routine sampling procedure is necessary to obtain data concerning the physical, chemical and biological characteristics of the waste stream regardless of the size or type of plant. *This information can be used for control of the treatment processes, to show that regulations or standards have been observed, for estimating the effect of plant effluent on the receiving waters and for design of plant extensions.*

SAMPLING

The purpose of sampling is to obtain smaller, more manageable quantities which truly represent the stream from which they are taken. Plant influent and effluent samples are to be 24-hour composites. Where 24-hour supervision of plant is not practised, it will be necessary to use automatic samplers. Most of the samplers now in use take samples at timed intervals ignoring flow variations. This tends to produce composites which place more importance on sewage sampled during low flows; all flow conditions are represented by equal volumes in the composites. An 8-hour composite is taken during the period when the plant is staffed, and combined with a 16-hour composite taken during the remainder of the day, in proportion with the flow during those periods (Figures 10-1 and 10-2). While some error cannot be avoided, the 24-hour composite represents the stream sampled better than a grab sample or even an 8-hour flow proportional sample taken during normal working hours. There are flow proportional

Figure 10-1: Flow proportional sampling. The composite correctly represents organic loading.



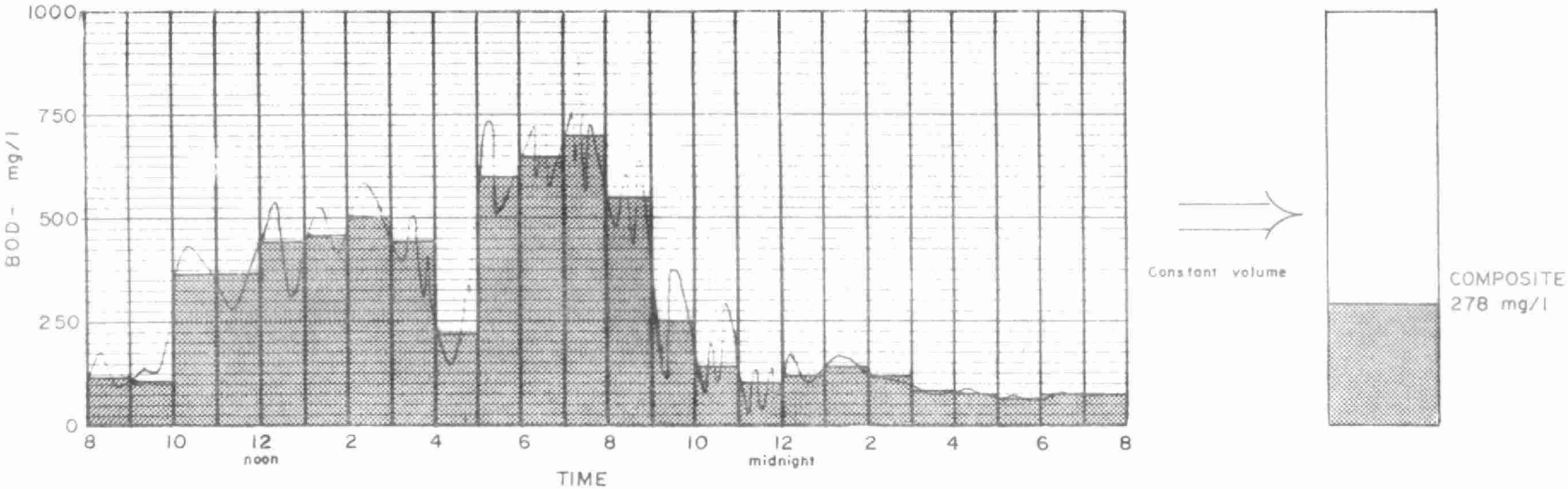


Figure 10-2: Constant aliquot sampling. Low flows (with little organic matter) are given the same weight in the composite as the daytime flows with higher concentrations.

samplers available but cost and complexity usually rule these out for routine plant sampling.

There are four basic types of automatic samplers available:

1) Vaccum type - vacuum is used to draw the sample into a metering chamber.
2) Pressure type - air pressure is used to eject the sample from a metering chamber submerged in the stream.
3) Bucket type - the sample is taken by a cup on a chain and dumped into a receptacle.
4) Diverter type - small continuous stream is pumped into a measuring device similar to a splitter box.

The type used will depend on sampling location and type of stream sampled.

Waste streams that fluctuate rapidly in quality require frequent sampling to obtain a representative composite. Other samples, such as sludge from a primary digester, are homogenous and are not subject to sudden changes; a single grab sample would be enough to characterize the contents of the entire digester for several days. Raw sludge, on the other hand, shows considerable variation, not only through the day but within a single pumping cycle. Judgement must be exercised as to the type and frequency of sampling to ensure representative results. Despite all the careful analysis using sophisticated equipment, the result obtained can be no better than the weakest link - the original sample.

LABORATORY TESTS

The processes within a plant, particularly biological processes, require constant and careful attention if they are to perform efficiently, and in some cases, if they are to perform at all. All the processes used in a sewage treatment plant (sedimentation, conversion

of dissolved matter to particulate matter, conversion of particulate matter to gases and inert products) occur in nature. The difference is time; the plant does in hours what occurs in nature in the course of many days. Because these functions are made to perform more rapidly, some method of controlling processes to obtain maximum efficiency from the plant is necessary. There are many tests which can be done even in the larger plants, because a few simple tests are enough to control the process. Those normally done in the plant depend on the equipment available and the experience of the operating personnel. Regardless of the sophistication of equipment and personnel available, only those tests necessary and relevant to controlling and assessing the processes should be carried out.

Choosing the analytical method requires some consideration. Since all sampling methods used are subject to sampling errors in varying degrees, the value of using precise analytical methods is questionable. Using the procedures in *STANDARD METHODS* offers many advantages: these methods have been thoroughly researched and developed and have an accepted legal status. They do not guarantee, however, that their use will automatically produce more accurate and more meaningful results. *STANDARD METHODS* specifies many details and precautions which are not always necessary or justified in routine work because:

1) the sample is not truly representative
2) the cost of analysis in time and money may be excessive,
3) many less precise results may have more meaning than a few precise ones.

The analyses done at plants, except the larger plants, are performed to control the process only.

Among the lab tests carried out are the following: Settleable Solids, Mixed Liquor Suspended Solids, Sludge Volume Index, Dry Solids, Total Solids, Volatile Solids, Dissolved Oxygen requirements, Volatile acids, Chlorine residuals.

Settleable Solids are measured on mixed liquor samples. In this simple test, fresh mixed liquor taken at the end of the aeration tank is allowed to settle for 30 minutes in a 1-liter graduated cylinder. During the first five or ten minutes of the settling period the activated sludge should be watched for settling characteristics. A slow settling sludge will produce a clear effluent but may not allow enough time for separation in the clarifier. This can result in floc being carried over the weirs. Very fast settling sludge, on the other hand, tends to leave small particles in suspension, producing a cloudy effluent.

Mixed Liquor Suspended Solids determinations are used to control the quantity of activated sludge available to stabilize the organic matter in the incoming sewage. Analysis for suspended solids is normally done by filtering a convenient sample size (say 100 ml) on a dried, weighed filter paper (glass fiber filters are easy to use and pick up very little moisture from the air), drying the filter at 103°C and weighing it. Weighing of the filter need be to three decimal places, at most. Because it is a grab sample, results are recorded only to the nearest 100 mg/l. In controlling plant processes suspended solids are sufficient because it can be assumed that the volatile portion will remain a constant proportion of the total suspended solids. However, *volatile suspended solids* should be used for comparison between plants *especially where one plant has phosphorus removal facilities.* Volatile solids are determined on the sample previously dried for suspended solids. (Ignition of the filtered samples at 550°C will not cause any loss in weight of the

glass fiber.)

At smaller plants a *centrifuge* is used to estimate mixed liquor suspended solids concentrations. The centrifuge reading (usually of a 15 ml sample) of the volume occupied by the solids is compared to a *calibration curve*. The calibration curve is prepared by plotting centrifuge readings against suspended solids determined by weighing. Since this method assumes a constant density of the compacted sludge which is rarely achieved, even a recently prepared calibration curve may be in error by 30 per cent.

Sludge Volume Index (SVI) is defined as the volume in milliliters occupied by one gram of sludge, in a one liter sample, after settling for thirty minutes. It is, therefore, calculated from the results of the 30-minute settling test and mixed liquor suspended solids determination. An average SVI is about 100 though it varies from plant to plant. The important thing to watch for is a change from the norm, because it signals a change in operation conditions and probably in effluent quality.

Dry Solids of other sludges are usually determined as *total solids* because of the difficulty in filtering concentrated sludges. The dissolved solids in raw sludge, for instance, amounts to no more than about 1000 mg/l. Assuming a sludge of 5% total solids (50,000 mg/l) the difference between total and suspended solids would be less than $\frac{1,000}{50,000} \times 100\% - 2\%$

Total solids are determined by weighing about 20 to 50 grams of sludge (to the nearest 0.1 gram is sufficient) and drying in an oven at $103^{0}C$. The dried residue should be weighed to two decimal places. Dry solids can then be calculated to two significant figures. *Volatile solids* can be determined on the dried sample by igniting it at $600^{o}C$ and calculating the weight loss. Volatile solids

measure the organic content of the sludge.

Dissolved oxygen determinations are performed regularly on aeration tank contents to ensure that sufficient oxygen is being supplied to permit *aerobic* stabilization of organic matter. In the presence of oxygen, the organics are eventually broken down into carbon dioxide, water, nitrates, sulfates and inert minerals, none of which produces an odour. In the absence of oxygen, the end products are carbon dioxide, methane, water, organic acids, alcohols, ammonia, hydrogen sulfide and a vile smelling dirty effluent. Both the Winkler method (including the HACH kit) and DO meters can provide accurate analysis for dissolved oxygen. Most DO meters in use now employ electrodes with plastic membranes through which the oxygen must diffuse. *Regular cleaning of the electrode and replacement of the membrane is required.* In using the Winkler method, manganous sulfate solution and alkaline iodide solution are added in excess to the sample. Under alkaline conditions the manganese ion is oxidized by the dissolved oxygen present (in direct relation to the amount of oxygen present). At this point, *as long as no more oxygen is introduced,* the test will not be affected by leaving it to do other jobs. When more sulfuric acid is added than is necessary to neutralize the added base, the oxidized manganese ions in acidic solution oxidize the iodide present to "free" iodine. Titration of the resulting solution must take place within a short time because the iodine will react with the organic material present. The sodium thiosulfate solution (or phenylarsene oxide, in the HACH kit) used must be measured accurately, since it measures the amount of iodine present. This in turn is directly proportional to the oxidized manganese, which is proportional to the dissolved oxygen in the sample. *The Miller method* is suitable for estimating oxygen levels near saturation and is subject to analyst errors. In this test, the oxygen present is titrated directly with ferrous iron in the

presence of tartrate to prevent formation of ferric hydroxide floc; after the oxygen is depleted the ferrous iron reduces methylene blue to a colorless compound. Because oxygen is constantly being used by bacteria, DO tests should be done on fresh grab samples.

Volatile Acids analysis in *anaerobic* digesters can help to control the digestion process. Acid formation is an intermediate step in anaerobic stabilization. An accumulation of an excess amount of acids can inhibit the next stage in the breakdown of organic matter, which is the formation of lower hydrocarbons (mostly methane) and carbon dioxide. Some digesters operate normally at 100 mg/l volatile acids as acetic acid, others at 1000 mg/l. Volatile acids should be monitored regularly for *change* in acid level as an indication of impending change(s) in the process. Most digesters are well buffered against change in pH by the *alkalinity*, which is available largely in the form of ammonium bicarbonate to neutralize the acids formed, maintaining a constant pH in the range where methane-forming bacteria can thrive. It should be noted that all digester failures are not due to, or signalled by, a rise in volatile acids content; heavy metal toxicity will produce digester failure with no change in volatile acids or pH.

Chlorine residuals are carried out on grab samples of plant effluent to ensure that adequate chlorine is being added to provide disinfection. While the treatment processes ahead of this stage remove a large portion of the organic matter, pathogenic (disease producing) bacteria and viruses will remain. In order to produce an effluent which is safe to re-use, disinfection using chlorine (or sodium hypochlorite) is employed. The method most commonly used to determine residual chlorine is a simple colour comparison method using orthotolidine. The development of the colour depends on time and temperature as well as the concentration of chlorine in solution.

Tests should be done for residual *total phosphorus* in the plant effluent where cost of phosphorus removal chemicals is high. This test involves boiling an effluent sample with potassium persulfate in the presence of an acid to convert the organic phosphates and the polyphosphate to ortho-phosphate. A colour (blue) is developed using an ammonium molybdate reagent and a reducing agent such as stannous chloride or aminonaphtholsulfonic acid (ANS). The colour is compared to a standard using a colorimeter or spectrophotometer, which can measure the intensity more accurately than the naked eye. Colour development is dependent on time and temperature and is affected by other ions in solution.

Other tests done by the Ministry laboratories and by larger plant laboratories are used to evaluate the performance of the plant and to estimate the effect of effluent discharge to the receiving stream. The most common analyses on plant influent and plant effluent are suspended solids, biochemical oxygen demand (BOD), total Kjeldahl nitrogen and total phosphorus.

RECORDS

Obtaining analytical data is not an end in itself. The results of analyses, together with flow data, sludge volumes, gas production, etc., must be recorded in an understandable (and easy to use) form before the data can be used. Because a plant is not operated by reacting to the sewage coming in at this particular moment, but on the *expected* qualities and concentrations based on average values over the past few weeks or months, it is necessary to maintain comprehensive up-to-date records. In particular, the aeration mixed liquor concentration cannot be varied from day to day to maintain a constant F/M because BOD tests require five days of incubation. From the records, however, it is possible to establish a range of mixed liquor concentrations in which the plant will produce an

acceptable effluent; the aeration tank will then be operated in the middle of this range to allow for variations in wasting and in influent strength.

Systems for recording data can be simple or complex depending on the purpose of the record, the complexity of the operation and the judgement of the operator. In any case, the system adopted should be realistic and applicable to the particular facility. The most effective way to handle data, especially where a large number of plants are concerned, is to record on preprinted forms. Samples of recorded sheets used by the Project Operations Branch of the Ministry of the Environment are shown in Figures - 10-3, 10-4, 10-5. The first, *Plant Performance*, is common to all plants, describing influent and effluent concentrations and quantities, grit removal, phosphorus removal and chlorination. The second, *Aeration Performance*, deals with aeration tanks and aerobic digester or holding tanks where they apply. The third, *Sludge Digestion and Disposal*, records the parameters used in describing anaerobic digestion and ultimate disposal of the sludge. The three sheets are for a complete record for conventional activated sludge plants; the first two are for high rate, contact stabilization and extended aeration plants; and the first and third, for primary treatment plants with anaerobic digestion.

However up-to-date and comprehensive these records may be, they are of little value, particularly in planning plant expansion, if the figures do not accurately represent what is happening at the plant. Most of the data recorded is not entirely independent, so they can be checked against each other. All flow metering should be checked regularly and if a tank is emptied for repairs, the indicated total flow required to fill the tank should be checked against a calculated volume of the tank. Sludge volumes can usually be checked by drawdown of a sump. To determine if the sampling is representative, *mass balances* can be done on various units within a plant. In any unit in the plant, the

Figure 10-3

WATER POLLUTION CONTROL PLANT

A – PLANT PERFORMANCE

PLANT ...., 19.... to............., 19.....

	MIN. FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG.
PLANT FLOWS										
MAXIMUM RATE – mgd	d									
MINIMUM RATE – mgd	d									
TOTAL DAILY FLOW – mil gal	d									
....										
....										
....										
BYPASS – in million gallons (estimate where meter readings are not available)										
PLANT	d									
PRIMARY CLARIFIERS	d									
AERATION SECTION	d									
CHLORINATION	d									
....										
....										
PLANT INFLUENT										
GRIT REMOVED – cu. ft.	when removed									
BOD – mg/l	1/w									
SUSPENDED SOLIDS – mg/l	1/w									
TOTAL PHOSPHORUS – mg/l	2/w									
TEMPERATURE – °C	d									
....										
....										
....										
PLANT EFFLUENT (including bypass)										
BOD – mg/l	1/w									
SUSPENDED SOLIDS – mg/l	1/w									
TOTAL PHOSPHORUS – mg/l	2/w									
....										
....										
....										
PHOSPHORUS REMOVAL CHEMICALS USED (record chemicals and quantity used)										
....	d									
....	d									
CHLORINATION										
Cl_2 to.............. – lb	d									
Cl_2 to effluent – lb	d									
EFFLUENT Cl_2 RESIDUAL – mg/l	d									
....										
....										

NOTE: Plants without equipment to perform the analyses should submit samples at least twice a month to the nearest MINISTRY OF THE ENVIRONMENT laboratory. The analyses requested should be checked off on the day the samples were taken.

REMARKS

Figure 10-4

WATER POLLUTION CONTROL PLANT

B – AERATION PERFORMANCE

PLANT .... 19... to .... 19...

	MIN FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG

AERATION INFLUENT (PRIMARY EFFLUENT)

TOTAL DAILY FLOW – mil gal	d									
BOD – mg/l	1/w									
SUSPENDED SOLIDS mg/l	1/w									
TOTAL PHOSPHORUS mg/l	1/w									
....										
....										
....										
....										

AERATION SECTION

NUMBER OF TANKS USED										
30 min. SETTLED SOLIDS ml/l	d									
MLSS mg/l	d									
MLVSS %	1/w									
MOHLMAN SVI	d									
AIR SUPPLIED – mil cu ft	d									
AER^n EFFLUENT TEMP. °C	d									
F/M lb BOD/day/lb MLSS	1/w									
DISS. OXYGEN mg/l (max./min)	d	/	/	/	/	/	/	/		
....										
....										

RETURN and WASTE ACTIVATED SLUDGE

RETURN SL. VOLUME mil gal	d									
% of FLOW TO AERATION	d									
SUSPENDED SOLIDS mg/l	1/w									
VOLATILE SOLIDS % of SS	1/w									
WASTE to .... -mil gal	d									
....										
....										
....										

SECONDARY EFFLUENT (if different from plant effluent)

BOD mg/l	1/w									
SUSPENDED SOLIDS mg/l	1/w									
TOTAL PHOSPHORUS mg/l	1/w									
....										
....										
....										
....										

AEROBIC DIGESTER or SLUDGE THICKENING TANK

30 min SETTLED SOLIDS ml/l	1/w									
SUSPENDEDED SOLIDS mg/l	When Removed									
VOLATILE SOLIDS % of SS										
VOLUME REMOVED gal										
SITE HAULED TO *										
....										

NOTE: * "SITE HAULED TO" – Use "L" for land application, "S" for sanitary landfill, "T" for transfer site (eg. storage lagoon), and "O" for others (specify). Designate each site by number (eg. L1, L2, S1, S2 etc) and keep a record of the locations.

REMARKS:

Figure 10-5

WATER POLLUTION CONTROL PLANT

C - SLUDGE DIGESTION and DISPOSAL

PLANT .... 19.... to .... 19.....

	MIN FREQ	MON	TUE	WED	THU	FRI	SAT	SUN	TOTAL	AVG
RAW SLUDGE										
GALLONS TO DIGESTER	d									
GALLONS TO	d									
TOTAL SOLIDS %	l/w									
VOLATILE SOLIDS % of T.S.	l/w									
....										
....										
PRIMARY DIGESTER										
TOTAL SOLIDS %	l/w									
VOLATILE SOLIDS % of T.S.	l/w									
ALKALINITY mg/l $CaCO_3$	l/w									
VOLATILE ACIDS mg/l HOAc	l/w									
TEMPERATURE deg C	d									
....										
DIGESTED SLUDGE										
GALLONS TO	WHEN REMOVED									
GALLONS TO										
TOTAL SOLIDS %										
VOLATILE SOLIDS % of T.S.										
....										
....										
SUPERNATANT										
GALLONS TO	WHEN REMOVED									
SUSPENDED SOLIDS mg/l										
....										
DIGESTER GAS										
PRODUCED 1000 cu. ft.	d									
WASTED 1000 cu. ft.	d									
SLUDGE HAULAGE										
LIQUID FROM .... cu.yd	WHEN HAULED									
- TOTAL SOLIDS %										
- SITE HAULED TO *										
DEWATERED FROM ...... cu.yd.										
- TOTAL SOLIDS %										
- SITE HAULED TO *										
....										
....										
....										

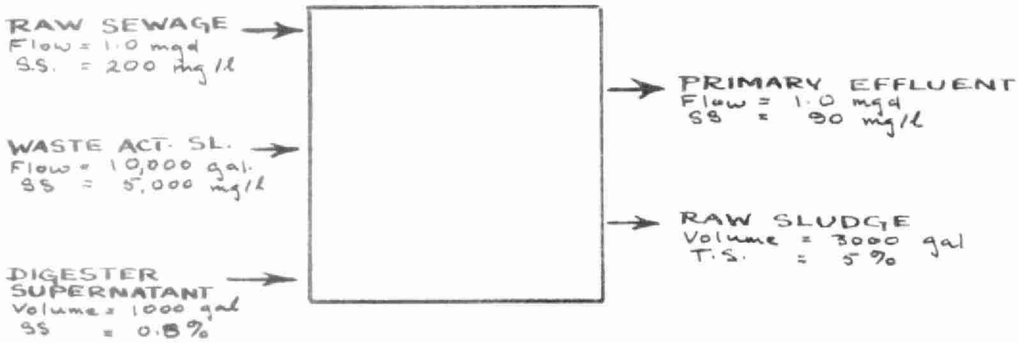
NOTE * "SITE HAULED TO": Use "L" for Land Application
"S" for Sanitary Landfill Site
"T" for Transfer Site (eg. storage lagoon)
"O" for Others (specify)

Designate each site by number (eg. L1, L2, S1, S2, etc.) and keep a record of the locations of these sites.

REMARKS

total weight of solids going into a tank must equal the total weight out.

In a conventional activated sludge plant and in primary plants, all solids removal by the plant are ultimately removed from the waste stream by the primary clarifier; these include solids in the raw sewage, waste activated sludge, digester supernatant, etc. The remainder of the solids appear in the primary effluent.



SOLIDS IN = $1.0 \times 10 \times 200$ (raw sewage)
$+ 0.01 \times 10 \times 5000$ (waste sl.)
$+ 1000 \times 10 \times \frac{0.8}{100}$ (supernatant)

= 2580 lb

SOLIDS OUT = $1.0 \times 10 \times 90$ (pr. eff)
$+ 3000 \times 10 \times \frac{5}{100}$ (raw sl.)

= 2400 lb.

SOLIDS IN should equal *SOLIDS OUT*. The above example agrees with 180 in 2500 (about 7%) and can be considered reasonable agreement. Assuming the metering is accurate, the major source of error is probably raw sludge sampling. It is not necessary to consider changes in volume due to waste activated sludge, digester supernatant or raw sludge pumping.

In activated sludge plants without primary clarifiers such as extended aeration plants, it is necessary modify the relation somewhat. In this case, assuming 1 pound of BOD produces 0.7 pound of MLSS, the mass

balance in the aeration tank becomes:

lb. Solids In = lb BOD x 0.7

lb. Solids Out = accumulation (or decrease) in MLSS (lb)
+ lb waste activated sludge
+ lb SS in effluent

The solids in the bottom of the clarifier can be ignored. However, in contact stabilization plants it is necessary to consider the solids in the reaeration tank.

Mass balances can be done on anaerobic digesters though a fairly long period of time should be used to establish average values. Again, solids in (in the form of raw sludge) equals solids out (as digested sludge and supernatant) and the solids lost to digestion.

Sampling points and/or methods should be altered, if necessary, to produce results which are consistent within the plant, that is, *for any unit within the plant, solids in plus accumulation must equal solids out plus destruction.*

CONCLUSIONS

Because plants are operated on the basis of what happened in the past, up-to-date records are necessary to operate a plant efficiently, following the trends in the changing sewage characteristics. In order to have reliable records, representative samples must be taken. Analysis of the samples will produce results by which the processes can be operated in the best range for that plant.

SUBJECT:

BASIC SEWAGE
TREATMENT OPERATION

TOPIC: 11

PRACTICAL MATH
FOR OPERATORS

OBJECTIVES:

Trainee will be able to:

1. Perform basic mathematical calculations in addition, subtraction, multiplication, division, ratio, decimals, units.

2. Perform practical mathematical calculations such as determining:
   - chlorine demand
   - flow through the plant
   - flow detention time
   - volume of sludge

3. Solve a sample problem using data from a typical activated sludge plant.

PRACTICAL MATH FOR SEWAGE PLANT OPERATORS

An operator of a wastewater treatment plant should routinely evaluate the efficiency of the plant and of the individual units. In most activated sludge plants routine laboratory tests are performed daily to ensure that the plant is effectively tuned to operate under optimum conditions. The analyses determined in the laboratory will assist the operator in deciding whether any adjustments are necessary to the treatment units to achieve a high degree of efficiency of operation.

This necessitates that the operator be able to apply the laboratory data made available to him. It is essential that he has a good sound knowledge of basic mathematics to fully understand the significance of the results.

The object of this presentation is to help the student recollect some of the mathematics he learned at school and be able to apply it to the sewage treatment process. In addition, it will prepare the student to appreciate more fully other related courses in this lecture series.

This course will review basic arithmetic, algebra and geometry. Methods of determining mathematical averages and means are also discussed. Several typical problems are outlined and solved under the various topics in the course. Tables listing the conversion units and proportional relations of geometric figures are also included. These can be used to assist you in solving the above problems and for future reference in relation to mathematical solutions at your own plant.

ARITHMETIC

Addition

The basic rule when adding numbers that have no decimals and which do not have the same number of digits (a single figure like 4, 7, 6, etc.) is to arrange them starting from the right hand side.

If the numbers contain units such as inches, feet, yards or pounds, etc., all the numbers must be changed to a similar unit before attempting the addition.

Example: add 4 inches, 3014 inches, 68 inches and 11,762 inches

```
    4 inches
 3014 inches
   68 inches
11762 inches
-----
   18
  13
  7
 4
1
-----
14848 inches
```

Subtraction

Subtraction is literally the inverse of addition but the arrangement of numbers is similar when preparing to carry out the subtraction.

Example: subtract 7413 from 621

```
 7413
- 621
-----
 6792
```

You can check your subtraction by adding the answer to the number being subtracted and the resulting answer should be the original or first number.

```
 6792
+ 621
-----
 7413 checks with the first number above.
```

You should develop a habit of mentally checking all your subtractions.

Example: subtract 8572 feet from 10,681 feet

```
 10,681 feet
- 8,572 feet
  2,109 feet   (answer)
 10,681 feet   (check)
```

Multiplication

Multiplication is essentially the process of adding a certain number a given number of times.

$$3 + 3 + 3 + 3 + 3 + 3 + 3 = 3 \times 7 = 21$$

It would be helpful at this stage to be thoroughly familiar with your multiplication table. If you are not, you should spend some time reviewing it.

The mathematical terminology of multiplication is:

$$\begin{array}{ccccc} \text{multiplicand} & \times & \text{multiplier} & = & \text{product} \\ 85 & \times & 31 & = & 2635 \end{array}$$

Example:

$$\begin{array}{r} 6231 \\ \times\ 42 \\ \hline 12462 \\ 24924 \\ \hline 261702 \end{array}$$

When multiplying two numbers, the units do not have to be identical. However, units as well as numbers have to be multiplied.

Example:

1. 4 yards x 8 yards = 32 (yds. x yds.) = 32 yds^2

2. 8 acres x 2 inches = 16 acre-inches

3. It takes 6 men to complete a job in 8 hours. Therefore we can say it took (6 men x 8 hours) 48 man-hours to do the work.

Two points you should bear in mind are:

1. (any number) x 1 = the number

2. (any number) x 0 = 0

Example: 432 x 1 = 432

407 x 0 = 0

Division

Division is the process of determining how many times one number is contained in another.

The mathematical notation is:

$$\text{divisor}\overline{)\text{dividend}}^{\;\text{quotient}}$$

```
       quotient
divisor/dividend
```

4 is contained in 8, 2 times

```
     2
4 / 8
```

Example: divide 261,702 by 42

This may also be expressed as $\dfrac{261{,}702}{42}$

or $261{,}702 \div 42$

```
    6231
42/261702
   252xxx
    97
    84
    130
    126
      42
      42
       0
```

The quotient (answer) is 6,231. In this case the divisor is contained in the dividend exactly 6,231 times. However, there could be a remainder as the following problem exemplifies.

Example: divide 8,472 by 76

```
    111
76/8472
   76xx
    87
    76
    112
     76
     36
```

answer: 111, remainder 36

The division can be checked by multiplying the divisor by the quotient and adding the remainder. This figure should check with the dividend if the computation was carried out correctly.

The following example illustrates a check of the above computation:

$$\begin{array}{r} 111 \\ \times\ 76 \\ \hline 666 \\ 777 \\ \hline 8436 \\ +\ 36 \\ \hline 8472 \end{array}$$

This answer checks with the original dividend therefore the answer is correct.

FRACTIONS

A fraction is an expression of one or more parts of a unit or a whole number. The various rules in dealing with the different operations using fractions namely, addition, subtraction, multiplication are presented below. The upper number of a fraction is known as the numerator and the lower one a denominator.

That is: $\frac{\text{numerator}}{\text{denominator}}$

Cancellation

A useful principle to bear in mind regarding fractions is that the value of a fraction is not altered if the numerator and denominator are multiplied or divided by the same number. This principle is known as the principle of cancellation.

Example: $\frac{2}{3} = \frac{2 \times 3}{3 \times 3} = \frac{6}{9}$

or $\frac{6}{9} = \frac{6 \div 3}{9 \div 3} = \frac{2}{3}$

However, the same principle does not apply if the same number is added to or subtracted from the numerator and denominator of a fraction.

$$\frac{3}{4} \text{ does not equal } (\neq) \ \frac{3+2}{4+2} = \frac{5}{6}$$

$$\text{or } \ \frac{3}{4} \neq \frac{3-1}{4-1} = \frac{2}{3}$$

- should explain more

The concept of these fundamentals is one of the most useful tools when working with fractions.

Addition and Subtraction

When fractions are to be added or subtracted it is necessary that the denominators of all fractions be identical. If they are not, we utilize the principles illustrated above. That is, we suitably change the numbers of the fraction without actually altering the value of the fraction and complete the required computation.

not very clear

The least common denominator is the lowest number that both denominators will divide into with nothing left over. In the case of the addition or subtraction of fractions, this is the number we try to obtain in all denominators. We then perform the required calculation as indicated in the problem using the numerators and express the resultant numerator over the common denominator.

Example: calculate $\frac{1}{2} + \frac{3}{4}$

The common denominator (the smallest number 2 and 4 divide into with no remainder) is 4. Express both fractions, without changing its value, having a denominator of 4.

$$\frac{1 \times 2}{2 \times 2} + \frac{3}{4} = \frac{2}{4} + \frac{3}{4}$$

Now complete the addition of the numerators and express the resultant numerator over the common denominator.

$$\frac{2}{4} + \frac{3}{4} = \frac{5}{4}$$

Example: calculate $\frac{1}{3} + \frac{3}{5} - \frac{1}{10}$

The common denominator is 30 because 3, 5 and 10 all divide into it with no remainder.

$$\frac{1 \times 10}{3 \times 10} + \frac{3 \times 6}{5 \times 6} - \frac{1 \times 3}{10 \times 3}$$

$$\frac{10}{30} + \frac{18}{30} - \frac{3}{30} = \frac{28}{30} - \frac{3}{30} = \frac{25}{30}$$

Fractions are generally reduced to their simplest form.

$$\frac{25 \div 5}{30 \div 5} = \frac{5}{6}$$

In some examples a whole number will be associated with a fraction (mixed fraction i.e. 4 7/8) and before any calculations are executed this expression should be changed to the fractional form (improper fraction i.e. $\frac{39}{8}$).

To change a mixed fraction to an improper fraction:

1. multiply the denominator by the whole number and add the result to the numerator.

2. express as an improper fraction by taking the result obtained in (1) as the numerator and the original denominator as the final denominator.

Example: express $3\frac{5}{8}$ as an improper fraction

$$\frac{(3 \times 8) + 5}{8} = \frac{29}{8}$$

Multiplication

The procedure for multiplying fractions is to multiply the numerators for the new numerator and the denominators for the new denominator.

Example: 1. compute $\frac{3}{4} \times \frac{5}{8}$

$$\frac{3}{4} \times \frac{5}{8} = \frac{15}{32}$$

2. $1\frac{3}{5} \times 2\frac{1}{3}$

$$\frac{(5 \times 1) + 3}{5} \times \frac{(3 \times 2) + 1}{3} = \frac{8}{5} \times \frac{7}{3}$$

$$= \frac{56}{15} = 56 \div 15 = 3\frac{11}{15}$$

Division

The procedure to follow when dividing fractions is to invert the divisor and multiply as described above.

Example: 1. invert the following numbers $\frac{3}{5}$, $\frac{1}{5}$ and 8

$\frac{3}{5}$ answer $\frac{5}{3}$

$\frac{1}{5}$ answer $\frac{5}{1} = 5$

8 answer $\frac{1}{8}$

Could explain why

2. $\frac{3}{5} \div \frac{4}{3}$

invert the divisor, then multiply

$$\frac{3}{5} \times \frac{3}{4} = \frac{9}{20}$$

3. $2\frac{1}{2} \div 1\frac{6}{7}$

$$= \frac{5}{2} \div \frac{13}{7} = \frac{5}{2} \times \frac{7}{13}$$

$$= \frac{35}{26} = 11\frac{11}{26}$$

Ratio

Ratio is a term which will be referred to in future lectures of this course. It is defined as a mathematical statement of the comparison of two quantities having the same units and expressed in the form of a simple fraction. For example, if plant A has a capacity of 6 mgd and plant B a capacity of 2 mgd, the ratio of the capacities of plant A to plant B is

$$\frac{6 \text{ mgd}}{2 \text{ mgd}} = \frac{3}{1} \text{ or } 3:1$$

Example: If a 1 mgd primary plant costs $300,000.00 and a 1 mgd conventional activated sludge plant costs $500,000.00 what is the ratio of costs?

$$\frac{\text{cost of primary plant}}{\text{cost of activated sludge plant}} = \frac{300,000}{500,000} = \frac{3}{5} \text{ or } 3:5$$

DECIMALS

A fraction could also be expressed in the decimal form. Decimals express fractions in multiples of 10, that is; tenths ($\frac{1}{10} = 0.1$), hundredths ($\frac{1}{100} = 0.01$) and thousandths ($\frac{1}{1000} = 0.001$) etc.

Example: $\frac{2}{10}$ is 0.2

$\frac{2}{100}$ is 0.02

$\frac{2}{1000}$ is 0.002

One of the most common uses of decimals is evidenced in the Canadian monetary system. (50 cents is 0.50 of a dollar, 37 cents is $\frac{37}{100}$ of a dollar or $0.37).

The term "decimal places" designates the number of figures to the right of a decimal point in a number. For example, 0.0321 is expressed to four decimal places. We may also have numbers in front of the decimal point as in 437.672. A good practice to follow when there are no numbers to the left of the decimal point is to represent this case by placing a zero immediately in front of the decimal point i.e. 0.863.

Adding and Subtracting Decimal Fractions

When arranging decimal fractions which are to be subtracted or added place the numbers in such a way that all the decimal points are in the same vertical column. If a number is shown with no decimal point, it is understood that a decimal point may be placed just to the right of the last figure in that number. That is, 383 is the same as 383.00. Annexing zeros after the last number of a decimal does not alter its value.

37.47 is the same as 37.4700
838 is the same as 838.000

Example: 1. add 431, 67.891, 24.37, 4, 0.010 and 3.125

$$\begin{array}{r} 431.000 \\ 67.891 \\ 24.370 \\ 4.000 \\ 0.010 \\ 3.125 \\ \hline 530.396 \end{array}$$

2. subtract 624.315 from 38.24

```
  624.315
-  38.240
  -------
  586.075   answer
  -------
  624.315   check
```

Multiplication of Decimal Fractions

The multiplication is performed in the usual manner and the answer will contain as many decimal places as the sum of decimal places in the multiplicand and multiplier (the numbers just multiplied).

Example: perform the multiplication 31.802 x 6.51

```
    31.802
   x 6.51     - a total of five decimal places
   -------      in the numbers being multiplied
     31802
   159010
  190812
  ---------
  207.03102   - a total of five decimal places in
                the product
```

Division of Decimal Fractions

When dividing a number containing a decimal fraction by another decimal fraction the following procedure applies.

1. Count the number of decimal places the decimal has to be moved to the right to make the divisor a whole number.
2. Move the decimal point in the dividend the number of decimal points to the right (adding zeros if necessary) as in (1). Essentially, the numerator and denominator have been multiplied by the same number, therefore, not changing the value of the fraction.
3. Divide keeping the decimal point in the quotient directly above the decimal point in the dividend and the units above the corresponding units of the dividend.

Example: divide 11.36 by 3.2

In accordance with the rules above:

1. 3.2 becomes 32 (a whole number). We have multiplied it by 10.

2. We also move the decimal one decimal point to the right in the dividend so that, 11.36 becomes 113.6. We have also multiplied it by 10.

3.
```
        3.55          check    3.55
  32/113.60                    x 32
     96                        7 10
     17 6                    106 5
     16 0                    113.60
      1 6 0
      1 6 0           checks with original dividend
          0           therefore the answer is correct.
```

PERCENT

Percent is a useful mathematical concept in any field since it gives one a clear comparison of efficiencies, loadings, etc. Literally "per" means "divided by" and "cent" means "hundred". Therefore, the whole is divided into 100 equal parts and the percent quoted is an expression of the part of the entire portion with which you are concerned. That is, 100% is the entire portion, 50% is one-half of the entire portion, 25% is one-quarter of the entire portion, 10% is one-tenth of the entire portion, etc.

Example: 1. What is 20% of 300

20% expressed as a fraction is $\frac{20}{100}$

Therefore 20% is $\frac{20}{100}$ or 0.20 of 300

$0.20 \times 300 = 60$

2. If a ton of sludge contains 90% water, what is the weight of water in the mixture.

one ton = 2,000 lb.

$0.90 \times 2000 = \frac{90}{100} \times 2000 = 1800$ lb. of water

EXPONENTIAL NUMBERS

For ease of expression numbers are often stated in an exponential form. This is especially the case for very large or small numbers. It is the technique of stating a number or performing a mathematical operation with the number to the power of 10:

Notation

$10^0 = 1$	$10^{-1} = \frac{1}{10}$	$= 0.10$
$10^1 = 10$	$10^{-2} = \frac{1}{100}$	$= 0.01$
$10^2 = 100$	$10^{-3} = \frac{1}{1000}$	$= 0.001$
$10^3 = 1,000$	$10^{-4} = \frac{1}{10000}$	$= 0.0001$
$10^4 = 10,000$	$10^{-5} = \frac{1}{100000}$	$= 0.00001$
$10^5 = 100,000$	$10^{-6} = \frac{1}{1000000}$	$= 0.000001$
$10^6 = 1,000,000$	$10^{-7} = \frac{1}{10000000}$	$= 0.0000001$

Rule 1. Any number to the power zero = 1

$$10^0 = 1$$

$$2^0 = 1$$

Rule 2. When numbers to a power of 10 are multiplied, the numbers are multiplied and the powers or exponents are added for the final answer.

$$3 \times 10^2 \times 2 \times 10^5 = 3 \times 2 \times 10^{5+2} = 6 \times 10^7$$

Rule 3. When two numbers to the power of 10 are divided, the numbers are divided and the exponent of the divisor is subtracted from the exponent of the dividend for the final answer.

$$9 \times 10^7 \div 3 \times 10^4$$

$$= \frac{9}{3} \times 10^{7-4} = 3 \times 10^3$$

Example: 1. express in the exponential form:

(a) $432 = 4.32 \times 100 = 4.32 \times 10^2$

(b) $0.0461 = \frac{4.61}{100} = 4.61 \times 10^{-2}$

(c) $2,000,000 = 2 \times 1,000,000 = 2 \times 10^6$

2. perform the indicated mathematical operation:

(a) $3 \times 10^4 \times 7 \times 10^5 = (3x7)10^{(4+5)} = 21 \times 10^9$

(b) $6.7 \times 10^{-2} \times 3.4 \times 10^7 = (6.7 \times 3.4)10^{(-2+7)}$
$= 22.78 \times 10^5$

(c) $4 \times 10^5 \div 2 \times 10^3 = \frac{4}{2} \times 10^{(5-3)} = 2 \times 10^2$

(d) $7.5 \times 10^7 \div 2.5 \times 10^4 = \frac{7.5}{2.5} \times 10^{(7-4)} = 3 \times 10^3$

UNITS

A unit is the term of reference in a mathematical statement i.e. in the expression 3 feet the unit is feet, in 14 yards the unit is yards. It describes the form of measurement being used in the expression or computation.

The most common forms of measurement are the English and metric systems. The U.S. system is identical to the English one except for liquid measure. All of these systems are used in Canada. Consequently, we must be able to readily convert from one system to another.

Rule 1. Concrete numbers associated with a physical unit can be added or subtracted only when they all possess the same physical unit.

3 feet + 2 yards = 3 feet + 6 feet = 9 feet

Rule 2. Concrete numbers, whether they have the same unit or not, can be multiplied or divided; however, a new unit is created since the units are subject to cancellation or multiplication.

Example: 1. solve

$$6 \text{ ft.} \times 3 \text{ ft.} = 18(\text{ft.} \times \text{ft.}) = 18 \text{ ft.}^2$$

2. A man drives 120 miles in 2 hours. At what speed is he driving?

$$\frac{120 \text{ miles}}{2 \text{ hours}} = 60 \text{ miles/hour}$$

means multiply to they know

1 hour = 60 minutes

$$3 \text{ hours } \left(\frac{60 \text{ minutes}}{\text{hour}}\right) = 180 \text{ minutes}$$

Note how the units are cancelled.

A conversion table is appended to this lecture to enable you to convert to the desirable unit system.

PARTS PER MILLION AND MILLIGRAMS PER LITRE

The terms parts per million (ppm) and milligrams per litre (mg/l) are used so extensively in the water and sewage works field to express analytical laboratory results that a complete section is devoted to its study. The latter term (mg/l)* (see below).

These units express a weight-to-weight ratio. They are used because of the high water dilution composing the sewage wastes. Basically, it is the weight of a substance, say in pounds, in one million pounds of the solvent.

The important conversion factor to remember is:

$$1 \text{ ppm} = \frac{1 \text{ milligram}}{1 \text{ litre}} = 1 \text{ mg/l}$$

* is used in the metric system of ratio expression

If we have 10 lb. of chlorine contained in 1,000,000 lb. of water, the concentration of chlorine in water may be expressed as follows:

$$\frac{10 \text{ lb.}}{1{,}000{,}000 \text{ lb.}} = 10 \text{ ppm}$$

Example: If we have a concentration of suspended solids (SS) of 15 ppm in a sewage effluent, approximately how many pounds of solids do we have in 100,000 gal. of sewage?

1 gal. of water = 10 lb.

It can be assumed that 1 gal. of sewage = 10 lb.

$$1 \text{ ppm} = \frac{1 \text{ lb.}}{100{,}000 \text{ gal}}$$

Concentration of solids = 15 ppm = $\dfrac{15 \text{ lb.}}{100{,}000 \text{ gal}}$
(or in the metric system 15 mg/l)

Therefore, we have 15 lb. of suspended solids for every 100,000 gallons of sewage.

ESTIMATE ANSWERS

When the operator is solving a mathematical problem he should mentally know in what range of magnitude to expect the answer. A common error is misplacing the decimal point in the final solution. When the problem has been solved, ask yourself; Does the answer make sense? It may save you from some embarrassing moments later when the answer is being quoted to your superiors.

CONVERSION UNITS

Multiply	By	To Obtain
ACRES	160	Square rods
Acres	4840	Square yards
Acres	43,560	Square feet
ACRES INCHES	27,154	Gallons
ACRES INCH/HR.	452	GPM
ATMOSPHERES (STD.) 760 MM of Mercury at 32°F.	14.696	Lbs./sq. inch
ATMOSPHERES	76.0	Cms. of mercury
Atmospheres	29.92	Inches of mercury
Atmospheres	33.90	Feet of water
Atmospheres	1.0333	Kgs./sq. cm.
Atmospheres	14.70	Lbs./sq inch
Atmospheres	1.058	Tons/sq. ft.
BARRELS-OIL	42	Gallons-Oil
BARRELS (Beer)	31.5	Gallons
(Wine)	31.0	Gallons
BRIT. THERM. UNITS	0.2520	Kilogram-calories
Brit. Therm. Units	777.5	Foot-lbs.
Brit. Therm. Units	3.927×10^{-4}	Horse-power-hrs.
Brit. Therm. Units	107.5	Kilogram-meters
Brit. Therm. Units	2.928×10^{-4}	Kilowatt-hrs.
B.T.U./MIN	12.96	Foot-lbs./sec.
B.T.U./min	0.02356	Horse-power
B.T.U./min	0.01757	Kilowatts
B.T.U./min	17.57	Watts
CENTARES (CENTIARES)	1	Square meters
CENTIGRAMS	0.01	Grams
CENTILETERS	0.01	Liters
CENTIMETERS	0.3937	Inches
Centimeters	0.03280	Feet
Centimeters	0.01	Meters
Centimeters	10	Millimeters
CENTIMTRS. OF MERC.	0.01316	Atmospheres
Centimtrs. of merc.	0.4461	Feet of water
Centimtrs. of merc.	136.0	Kgs./sq. meter
Centimtrs. of merc.	27.85	Lbs./sq. ft.
Centimtrs. of merc.	0.1934	Lbs./sq. inch
CENTIMTRS./SECOND	1.969	Feet/min.
Centimtrs./second	0.03281	Feet/sec.
Centimtrs./second	0.036	Kilometers/hr.
Centimtrs./second	0.6	Meters/min.
Centimtrs./second	0.02237	Miles/hr.
Centimtrs./second	3.728×10^{-4}	Miles/min.
CMS./SEC./SEC.	0.03281	Feet/sec./sec.
CUBIC CENTIMETERS	3.531×10^{-5}	Cubic feet
Cubic centimeters	6.102×10^{-2}	Cubic inches
Cubic centimeters	10^{-6}	Cubic meters
Cubic centimeters	1.308×10^{-6}	Cubic yards
Cubic centimeters	2.642×10^{-4}	Gallons
Cubic centimeters	10^{-3}	Liters
Cubic centimeters	2.113×10^{-3}	Pints (liq.)
Cubic centimeters	1.057×10^{-3}	Quarts (liq.)

Multiply	By	To Obtain
CUBIC FEET	2.832×10^{4}	Cubic cms.
Cubic feet	1728	Cubic inches
Cubic feet	0.02832	Cubic meters
Cubic feet	0.03704	Cubic yards
Cubic feet	7.48052	Gallons U.S.
Cubic feet	6.23	Imper. Gallons
Cubic feet	28.32	Liters
Cubic feet	59.84	Pints (liq.)
Cubic feet	29.92	Quarts (liq.)
CUBIC FEET/MINUTE	472.0	Cubic cms./sec.
Cubic feet/minute	0.1247	Gallons/sec.
Cubic feet/minute	0.4720	Liters/sec.
Cubic feet/minute	62.43	Lbs. of water/min.
CUBIC FEET/SECOND	0.646317	Million gals./day
Cubic feet/second	448.831	Gallons/min.
CUBIC FOOT WATER	62.4	Pounds
Cubic foot water	998.8	Ounces
Cubic foot water	28.315	Kilograms
CUBIC INCHES	16.39	Cubic centimeters
Cubic inches	5.787×10^{-4}	Cubic feet
Cubic inches	1.639×10^{-5}	Cubic meters
Cubic inches	2.143×10^{-5}	Cubic yards
Cubic inches	4.329×10^{-3}	Gallons
Cubic inches	1.639×10^{-2}	Liters
Cubic inches	0.03463	Pints (liq.)
Cubic inches	0.01732	Quarts (liq.)
CUBIC METERS	10^{6}	Cubic centimeters
Cubic meters	35.31	Cubic feet
Cubic meters	61,023	Cubic inches
Cubic meters	1.308	Cubic yards
Cubic meters	264.2	Gallons U.S.
Cubic meters	220	Imperial Gallons
Cubic meters	10^{3}	Liters
Cubic meters	2113	Pints (liq.)
Cubic meters	1057	Quarts (liq.)
CUBIC YARDS	7.646×10^{5}	Cubic centimeters
Cubic yards	27	Cubic feet
Cubic yards	46,656	Cubic inches
Cubic yards	0.7646	Cubic meters
Cubic yards	202.0	Gallons
Cubic yards	764.6	Liters
Cubic yards	1616	Pints (liq.)
Cubic yards	807.9	Quarts (liq.)
CUBIC YARDS/MIN.	0.45	Cubic feet/sec.
Cubic yards/min.	3.367	Gallons/sec.
Cubic yards/min.	12.74	Liters/sec.
DECIGRAMS	0.1	Grams
DECILITERS	0.1	Liters
DECIMETERS	0.1	Meters
DEGREES (ANGLE)	60	Minutes
Degrees (angle)	0.01745	Radians
Degrees (angle)	3600	Seconds
DEGREES/SEC.	0.01745	Radians/sec.
Degrees/sec.	0.1667	Revolutions/min.
Degrees/sec.	0.002778	Revolutions/sec.
DEKAGRAMS	10	Grams

CONVERSION UNITS

Multiply	By	To Obtain
DEKALITERS	10	Liters
DEKAMETERS	10	Meters
DRAMS	27.34375	Grains
Drams	0.0625	Ounces
Drams	1.771845	Grams
FATHOMS	6	Feet
FEET	30.48	Centimeters
Feet	12	Inches
Feet	0.3048	Meters
Feet	1/3	Yards
FEET OF WATER	0.02950	Atmospheres
Feet of water	0.8826	Inches of mercury
Feet of water	0.03048	Kgs./sq. cm.
Feet of water	62.43	Lbs./sq. ft.
Feet of water	0.4335	Lbs./sq. inch
FEET/MIN.	0.5080	Centimeters/sec.
Feet/min.	0.01667	Feet/sec.
Feet/min.	0.01829	Kilometers/hr.
Feet/min.	0.3048	Meters/min.
Feet/min.	0.01136	Miles/hr.
FEET/SEC./SEC.	30.48	Cms./sec./sec.
Feet/sec./sec.	0.3048	Meters/sec./sec.
FOOT-POUNDS	$1.286x10^{-3}$	Br. Thermal Units
Foot-pounds	$5.050x10^{-7}$	Horse-power-hrs.
Foot-pounds	$3.241x10^{-4}$	Kilogram-calories
Foot-pounds	0.1383	Kilogram-meters
Foot-pounds	$3.766x10^{-7}$	Kilowatt-hrs.
FOOT-POUNDS/MIN.	$1.286x10^{-3}$	B. T. Units/min.
Foot-pounds/min.	0.01667	Foot-pounds/sec.
Foot-pounds/min.	$3.030x10^{-5}$	Horse-power
Foot-pounds/min.	$3.241x10^{-4}$	Kg.-calories/min.
Foot-pounds/min.	$2.260x10^{-5}$	Kilowatts
FOOT-POUNDS/SEC.	$7.717x10^{-2}$	B. T. Units/min.
Foot-pounds/sec.	$1.818x10^{-3}$	Horse-power
Foot-pounds/sec.	$1.945x10^{-2}$	Kg.-calories/min.
Foot-pounds/sec.	$1.356x10^{-3}$	Kilowatts
GALLONS	3785	Cubic centimeters
Gallons	0.1337	Cubic feet
Gallons	231	Cubic inches
Gallons	$3.785x10^{-3}$	Cubic meters
Gallons	$4.951x10^{-3}$	Cubic yards
Gallons	128	Fluid ounces
Gallons	3.785	Liters
Gallons	8	Pints (liq.)
Gallons	4	Quarts (liq.)
GALLONS, IMPERIAL	1.20095	U.S. Gallons
Gallons, U.S.	0.83267	Imperial gallons
Gallons Imperial	277.3	Cubic inches
Gallons Imperial	0.16	Cubic foot
Gallons Imperial	4.546	Liters
Gallons Imperial	0.00454	Cubic meter
GALLONS WATER	8.3453	Pounds of water
GALS. WATER (U.S.)	3.785	Kilograms

Multiply	By	To Obtain
GALS. WATER (IMP.)	10.02	Pounds
Gals. water (Imp.)	4.54	Kilograms
GALLONS/MIN.	$2.228x10^{-3}$	Cubic feet/sec.
Gallons/min.	0.06308	Liters/sec.
Gallons/min.	8.0208	Cu. ft./hr.
GALLONS WATER/MIN.	6.0086	Tons water/24 hrs.
GRAINS (TROY)	1	Grains (avoir.)
Grains (troy)	0.06480	Grams
Grains (troy)	0.04167	Pennyweights (troy)
Grains (troy)	$2.0833x10^{-3}$	Ounces (troy)
GRAINS/U.S. GAL.	17.118	Parts/million
Grains/U.S. gal.	142.86	Lbs./million gal.
GRAINS/IMP. GAL.	14.286	Parts/million
GRAMS	980.7	Dynes
Grams	15.43	Grains
Grams	10^{-3}	Kilograms
Grams	10^{3}	Milligrams
Grams	0.03527	Ounces
Grams	0.03215	Ounces (troy)
Grams	$2.205x10^{-3}$	Pounds
GRAMS/CM.	$5.600x10^{-3}$	Pounds/inch
GRAMS/CU. CM.	62.43	Pounds/cubic foot
Grams/cu. cm.	0.03613	Pounds/cubic inch
GRAMS/LITER	58.417	Grains/gal.
Grams/liter	8.345	Pounds/1000 gals.
Grams/liter	0.062427	Pounds/cubic foot
Grams/liter	1000	Parts/million
HECTOGRAMS	100	Grams
HECTOLITERS	100	Liters
HECTOMETERS	100	Meters
HECTOWATTS	100	Watts
HORSE-POWER	42.44	B. T. Units/min.
Horse-power	33,000	Foot-lbs./min.
Horse-power	550	Foot-lbs./sec.
Horse-power	1.014	H-power (Metric)
Horse-power	10.70	Kg.-calories/min.
Horse-power	0.7457	Kilowatts
Horse-power	745.7	Watts
HORSE-POWER (BOILER)	33,479	B. T. U./hr.
Horse-power (boiler)	9.803	Kilowatts
HORSE-POWER-HOURS	2547	Br. Thermal Units
Horse-power-hours	$1.98x10^{6}$	Foot-lbs.
Horse-power-hours	641.7	Kilogram-calories
Horse-power-hours	$2.737x10^{5}$	Kilogram-meters
Horse-power-hours	0.7457	Kilowatt-hours
INCHES	2.540	Centimeters
Inches	25.4	Millimeters
Inches	.0254	Meters
Inches	.0833	Foot
INCHES OF MERCURY	0.03342	Atmospheres
Inches of mercury	1.133	Feet of water

CONVERSION UNITS

Multiply	By	To Obtain
Inches of mercury	0.03453	Kgs./sq. cm.
Inches of mercury	70.73	Lbs./sq. ft.
Inches of mercury	0.4912	Lbs./sq. inch
INCHES OF WATER	0.002458	Atmospheres
Inches of water	0.07355	Inches of mercury
Inches of water	0.002540	Kgs./sq. cm.
Inches of water	0.5781	Ounces/sq. inch
Inches of water	5.202	Lbs./sq. foot
Inches of water	0.03613	Lbs./sq. inch
KILOGRAMS	980,665	Dynes
Kilograms	2.205	Lbs.
Kilograms	1.102×10^{-3}	Tons (short)
Kilograms	10^{3}	Grams
KGS./METER	0.6720	Lbs./foot
KGS./SQ. CM.	0.9678	Atmospheres
Kgs./sq. cm.	32.81	Feet of water
Kgs./sq. cm.	28.96	Inches of mercury
Kgs./sq. cm.	2048	Lbs./sq. foot
Kgs./sq. cm.	14.22	Lbs./sq. inch
KGS./SQ. MILLIMETER	10^{6}	Kgs./sq. meter
KILOLITERS	10^{3}	Liters
KILOMETERS	10^{5}	Centimeters
Kilometers	3281	Feet
Kilometers	10^{3}	Meters
Kilometers	0.6214	Miles
Kilometers	1094	Yards
KILOMETERS/HR.	27.78	Centimeters/sec.
Kilometers/hr.	54.68	Feet/min.
Kilometers/hr.	0.9113	Feet/sec.
Kilometers/hr.	0.5396	Knots
Kilometers/hr.	16.67	Meters/min.
Kilometers/hr.	0.6214	Miles/hr.
KMS./HR./SEC.	27.78	Cms./sec./sec.
Kms./hr./sec.	0.9113	Ft./sec./sec.
Kms./hr./sec.	0.2778	Meters/sec./sec.
KILOWATTS	56.92	B. T. Units/min.
Kilowatts	4.425×10^{4}	Foot-lbs./min.
Kilowatts	737.6	Foot-lbs./sec.
Kilowatts	1.341	Horse-power
Kilowatts	14.34	Kg.-calories/min.
Kilowatts	10^{3}	Watts
KILOWATT-HOURS	3415	Br. Thermal Units
Kilowatt-hours	2.655×10^{6}	Foot-lbs.
Kilowatt-hours	1.341	Horse-power-hrs.
Kilowatt-hours	860.5	Kilogram-calories
Kilowatt-hours	3.671×10^{5}	Kilogram-meters
LITERS	10^{3}	Cubic centimeters
Liters	0.03531	Cubic feet
Liters	61.02	Cubic inches
Liters	10^{-3}	Cubic meters
Liters	1.308×10^{-3}	Cubic yards
Liters	0.2642	Gallons
Liters	2.113	Pints (liq.)
Liters	1.057	Quarts (liq.)
LITERS/MIN.	5.886×10^{-4}	Cubic ft./sec.
Liters/min.	4.403×10^{-3}	Gals./sec.

Multiply	By	To Obtain
LUMBER WIDTH (IN.) X THICKNESS (IN.) / 12	Length (ft.)	Board Feet
METERS	100	Centimeters
Meters	3.281	Feet
Meters	39.37	Inches
Meters	10^{-3}	Kilometers
Meters	10^{3}	Millimeters
Meters	1.094	Yards
METERS/MIN.	1.667	Centimeters/sec.
Meters/min.	3.281	Feet/min.
Meters/min.	0.05468	Feet/sec.
Meters/min.	0.06	Kilometers/hr.
Meters/min.	0.03728	Miles/hr.
METERS/SEC.	196.8	Feet/min.
Meters/sec.	3.281	Feet/sec.
Meters/sec.	3.6	Kilometers/hr.
Meters/sec.	0.06	Kilometers/min.
Meters/sec.	2.237	Miles/hr.
Meters/sec.	0.03728	Miles/min.
METRIC TONS	2204.6	Pounds
Metric tons	1.1023	Short tons
MICRONS	10^{-6}	Meters
MILES	1.609×10^{5}	Centimeters
Miles	5280	Feet
Miles	1.609	Kilometers
Miles	1760	Yards
MILES/HR.	44.70	Centimeters/sec.
Miles/hr.	88	Feet/min.
Miles/hr.	1.467	Feet/sec.
Miles/hr.	1.609	Kilometers/hr.
Miles/hr.	0.8684	Knots
Miles/hr.	26.82	Meters/min.
MILES/MIN.	2682	Centimeters/sec.
Miles/min.	88	Feet/sec.
Miles/min.	1.609	Kilometers/min.
Miles/min.	60	Miles/hr.
MILLIERS	10^{3}	Kilograms
MILLIGRAMS	10^{-3}	Grams
MILLILITERS	10^{-3}	Liters
MILLIMETERS	0.1	Centimeters
Millimeters	0.03937	Inches
MILLIGRAMS/LITER	1	Parts/million
MILLION GALS./DAY	1.54723	Cubic ft./sec.
MINER'S INCHES	1.5	Cubic ft./min.
Miner's inches (Arizona, Cal., Mont., Nevada, Oregon)	11.25	G.P.M.

CONVERSION UNITS

Multiply	By	To Obtain
(Idaho, Kansas, Neb., N.M., N.D., S.D., Utah)	9	G.P.M.
MINUTES (ANGLE)	2.909×10^{-4}	Radians
OUNCES	16	Drams
Ounces	437.5	Grains
Ounces	0.0625	Pounds
Ounces	28.349527	Grams
Ounces	0.9115	Ounces (troy)
Ounces	2.790×10^{-5}	Tons (long)
Ounces	2.835×10^{-5}	Tons (metric)
OUNCES, TROY	480	Grains
Ounces, troy	20	Pennywghts. (troy)
Ounces, troy	0.08333	Pounds (troy)
Ounces, troy	31.103481	Grams
Ounces, troy	1.09714	Ounces, avoir.
OUNCES (FLUID)	1.805	Cubic inches
Ounces (fluid)	0.02957	Liters
OUNCES/SQ. INCH	0.0625	Lbs./sq. inch
PARTS/MILLION	0.0584	Grains/U.S. gal.
Parts/million	0.07016	Grains/Imp. gal.
Parts/million	8.345	Lbs./million gal.
PENNYWGHTS. (TROY)	24	Grains
Pennywghts. (troy)	1.55517	Grams
Pennywghts. (troy)	0.05	Ounces (troy)
Pennywghts. (troy)	4.1667×10^{-3}	Pounds (troy)
PINTS	0.4732	Liter
POUNDS (AVOIR.)	16	Ounces
Pounds (avoir.)	256	Drams
Pounds (avoir.)	7000	Grains
Pounds (avoir.)	0.0005	Tons (short)
Pounds (avoir.)	453.5924	Grams
Pounds (avoir.)	1.21528	Pounds (troy)
Pounds (avoir.)	14.5833	Ounces (troy)
Pounds (avoir.)	0.454	Kilograms
POUNDS (TROY)	5760	Grains
Pounds (troy)	240	Pennywghts. (troy)
Pounds (troy)	12	Ounces (troy)
Pounds (troy)	373.24177	Grams
Pounds (troy)	0.822857	Pounds (avoir.)
Pounds (troy)	13.1657	Ounces (avoir.)
Pounds (troy)	3.6735×10^{-4}	Tons (long)
Pounds (troy)	4.1143×10^{-4}	Tons (short)
Pounds (troy)	3.7324×10^{-4}	Tons (metric)
POUNDS OF WATER	0.01602	Cubic feet
Pounds of water	27.68	Cubic inches
Pounds of water	0.1198	Gallons
Pounds of water	0.10	Imp. gallon
LBS. OF WATER/MIN.	2.670×10^{-4}	Cubic ft./sec.
POUNDS/CUBIC FOOT	0.01602	Grams/cubic cm.
Pounds/cubic foot	16.02	Kgs./cubic meter
Pounds/cubic foot	5.787×10^{-4}	Lbs./cubic inch
POUNDS/CUBIC INCH	27.68	Grams/cubic cm
Pounds/cubic inch	2.768×10^{4}	Kgs./cubic meter
Pounds/cubic inch	1728	Lbs./cubic foot
POUNDS/FOOT	1.488	Kgs./meter
Pounds/inch	178.6	Grams/cm.
POUNDS/SQ. FOOT	0.01602	Feet of water
Pounds/sq. foot	4.883×10^{-4}	Kgs./sq. cm.
Pounds/sq. foot	6.945×10^{-3}	Pounds/sq. inch
POUNDS/SQ. INCH	0.06804	Atmospheres
Pounds/sq. inch	2.307	Feet of water
Pounds/sq. inch	2.036	Inches of mercury
Pounds/sq. inch	0.07031	Kgs./sq. cm.
QUARTS (DRY)	67.20	Cubic inches
QUARTS (LIQ.)	57.75	Cubic inches
QUINTAL, ARGENTINE	101.28	Pounds
Quintal, Brazil	129.54	Pounds
Quint., Castile, Peru	101.43	Pounds
Quintal, Chile	101.41	Pounds
Quintal, Mexico	101.47	Pounds
Quintal, Metric	220.46	Pounds
$\dfrac{1}{\text{SQ. FT./GAL./MIN.}}$	8.0208	Overflow rate (ft./hr.)
TEMP. (°C.)+273	1	Abs. temp. (°C.)
Temp. (°C.)+17.78	1.8	Temp. (°F.)
Temp. (°F.)+460	1	Abs. temp. (°F.)
Temp. (°F.)−32	5/9	Temp. (°C.)
TONS (LONG)	1016	Kilograms
Tons (long)	2240	Pounds
Tons (long)	1.12000	Tons (short)
TONS (METRIC)	10^{3}	Kilograms
Tons (metric)	2205	Pounds
TONS (SHORT)	2000	Pounds
Tons (short)	32000	Ounces
Tons (short)	907.18486	Kilograms
Tons (short)	2430.56	Pounds (troy)
Tons (short)	0.89287	Tons (long)
Tons (short)	29166.66	Ounces (troy)
Tons (short)	0.90718	Tons (metric)
TONS OF WATER/24 HRS.	83.333	Pounds water/hr.
Tons of water/24 hrs.	0.16643	Gallons/min.
Tons of water/24 hrs.	1.3349	Cu. ft./hr.
WATTS	0.05692	B. T. Units/min.
Watts	44.26	Foot-pounds/min.
Watts	0.7376	Foot-pounds/sec.
Watts	1.341×10^{-3}	Horse-power
Watts	0.01434	Kg.-calories/min.
Watts	10^{-3}	Kilowatts
WATT-HOURS	3.415	Br. Thermal Units
Watt-hours	2655	Foot-pounds
Watt-hours	1.341×10^{-3}	Horse-power hrs.
Watt-hours	0.8605	Kilogram-calories
Watt-hours	367.1	Kilogram-meters
Watt-hours	10^{-3}	Kilowatt-hours

ALGEBRA

Algebra is a branch of mathematics that deals with the relation of quantities or properties of numbers by means of general symobls. Furthermore, manipulations of these symbols are executed according to defined laws to express the mathematical statement in a desired form.

Clarification of these statements is, undoubtedly, in order. In algebra letters are used to represent an unknown quantity. For example, there is a certain number of people in a room. We let a letter say "x" represent this unknown quantity.

In some algebraic expressions there may be several unknown quantities constituting an equation. An equation is simply a statement of equality to two quantities.

Example:

The following algebraic expressions are equations:

$$4x + 1 = 17$$
$$9x + y = 3a$$
$$2bc + 8 = 14s$$

In most practical cases we will have one unknown quantity for each equation; however, we may have to rearrange the numbers in the equation to isolate the letter whose value is to be computed.

Example: Solve for x

1. $x + 3 = 9$
   $x = 6$

2. $2x + 8 = 18$
   $2x = 18 - 8 = 10$
   $x = \frac{10}{2} = 5$

The solutions to the above problems are fairly obvious. We are often faced with more complicated forms of algebraic equations for which we seek solutions. To correctly isolate a particular letter in an equation the following principles have been established to govern the rearrangement in an equation:

The values of the unknown quantities in an equation are not altered if:

(a) Equal numbers are added to or subtracted from both sides of the equation.

$$a + 7 = 11$$
subtract seven from both sides
$$a + 7 - 7 = 11 - 7$$
$$a = 4$$

(b) Both sides of the equation are multiplied or divided by equal numbers.

$$3a = 9$$

divide both sides by 3

$$\frac{3a}{3} = \frac{9}{3}$$

$$a = 3$$

(c) Equal powers or roots are applied to both sides of the equation.

$$x^2 = 9$$

take the square root of both sides

$$x = 3$$

A knowledge of the fundamentals of algebra is a definite asset when formulae are applied to the solutions of mathematical problems.

A mathematical formula is a general rule or principle which is expressed in algebraic symbols in the form of an equation. Formulae are often developed to simplify mathematical computations and to assist the operator in interpreting the results of the various sewage treatment plant control tests. Several formulae will be introduced in this course so a comprehension of their algebraic concepts is essential if the formulae are to be applied to specific cases.

Example.

The general formula for the sludge volume index of the activated sludge process is

$$\text{Sludge volume index} = \frac{\text{\% settleable solids}}{\text{ppm suspended solids}} \times 10{,}000$$

or it can be expressed as

$$\text{S.V.I.} = \frac{a}{b} \times 10{,}000$$

where: a = % settleable solids (of the 30-minute settling test)

b = ppm of suspended solids (in the aeration tank)

We now apply this general formula to a specific condition.

(a) What is the S.V.I. if;

$$a = 25\% \text{ and } b = 3000 \text{ ppm}$$

$$S.V.I. = \frac{a}{b} \times 10{,}000 = \frac{25}{3000} \times 10{,}000$$

$$S.V.I = 83$$

The S.V.I is usually recommended to be in the range of 80 - 100. Therefore, the operator can assume that the sludge is in a favourable settling range.

(b) What should the MLSS content be if the 30-minute settling test is 28%.

$$\text{Assume } S.V.I. = 100$$

$$a = 28\%, \quad b = ?$$

$$S.V.I. = \frac{a}{b} \times 10{,}000$$

Rearranging the equation to isolate "b", we obtain (by rule B)

$$b = \frac{a}{(SVI)} \times 10{,}000$$

Substituting, we get

$$b = \frac{28}{100} \times 10{,}000$$

$$b = 2800 \text{ ppm}$$

(c) $4x + y = 16z + 12$, solve for x if $y = 8$, and $z = 1$

First we isolate the x

(i) Subtract y from both sides of the equation (rule A)

$$4x + y - y = 16z + 12 - y$$

$$4x = 16z + 12 - y$$

(ii) Divide the equation by 4 and cancel (rule B).

$$\frac{4x}{4} = \frac{16z + 12 - y}{4}$$

$$x = 4z + 3 - \frac{y}{4}$$

(iii) We have isolated the unknown and now we substitute.

$$x = 4 \times 1 + 3 - \frac{8}{4} = 4 + 3 - 2$$

$$x = 5$$

The latter example was more difficult than the first two; however, it illustrates the guidance of the rules presented earlier in isolating the unknown factor and then simply substituting. You may require further practice in these exercises to gain skill in rapid manipulation to isolate the unknown quantity.

GEOMETRY

Plane geometry is a branch of mathematics that deals with the measurement and relationship of points, lines, angles and surfaces. Our interest lies in determining the area of surfaces, the volume of solids and the capacity of the various treatment units. A table listing the formulae of areas and volumes of popular geometric shapes is appended to these lecture notes for your reference.

Example:

(1) How many square feet are contained in a plot of land 400 ft. x 625 ft?

Area = 400 ft. x 625 ft. = 250,000 ft.^{2}

(2) What is the area of a circle with a radius of 10 feet?

$$A = \pi r^2$$

π = 3.1416 (for most practical calculations at a sewage treatment plant π = 3.14 will suffice in accuracy)

$$r = 10 \text{ ft.}$$

$$A = 3.14 \times 10^2 \text{ ft.}^2$$
$$A = 3.14 \times 100 \text{ ft.}^2$$
$$A = 314 \text{ ft.}^2$$

Note the importance of carrying the unit (ft^2, etc.) in our calculations.

(3) Compute the volume of a cylinder having the following dimensions;

$L = 5$ in., $d = 4$ in.

$$\text{Volume} = \text{Area of circular top} \times \text{height}$$
$$= \frac{\pi d^2}{4} \times L$$
$$= \frac{3.14 \times 4^2 \times 5 \text{ in.}^2}{4} = \frac{3.14 \times 16 \times 5 \text{ in.}^2}{4}$$
$$= 62.80 \text{ in.}^3$$

An important function of the sewage treatment plant operator is to keep his plant effectively tuned to operate at peak efficiency. There are various laboratory control tests which can be performed to guide the operator in this respect. However, most tests require the use of mathematics to enable the operator to interpret the results of the tests.

In addition, he should keep a check on the working load of the operational equipment at the plant. The design capacity of each piece of equipment should be recorded and tests should be routinely conducted to determine if the equipment has lost any of its efficiency. This will allow the accounting staff to consider the budgetary impact for replacement of equipment or plant expansion as far in advance as possible.

Some typical examples illustrating the need of mathematics in carrying out these duties are presented. A complete comprehension of these techniques will guide the student in conducting similar tests at his plant.

Rate of Flow

The rate of flow is the volume of water flowing past a given point in a unit of time. It is often applied when determining the flow of water in a stream or expressing pump or plant capacities.

Rate of flow = wetted area of channel x velocity of flow

$Q = v \times A$ (formula for flow in a channel)

or Q = Volume/time = V/t (formula for rating pump capacities etc.)

Example: Stream flow

(1) What is the rate of flow of water in a stream that is 3 feet deep and 5 feet wide if the velocity of the water is 2 feet per second?

$$Q = v \times A$$

where: Q = rate of discharge (ft.^{3}/sec.)
v = velocity (ft./sec.)
A = area (ft.^{2})

$$Q = 2 \frac{\text{ft.}}{\text{sec.}} \times (3 \times 5) \text{ ft.}^2$$

$$Q = 30 \text{ ft.}^3/\text{sec.} = 30 \text{ cfs}$$

What is a simple method of approximating the velocity of the water in a small stream?

Example: Determining the capacity of a pump

(2) What is the capacity of a pump in Imperial gallons per minute that can fill a rectangular tank 30 feet long by 10 feet wide by 6 feet deep in 1 hour and 30 minutes?

Q = Volume/time

Volume of the tank = 30 ft. x 10 ft. x 6 ft.
= 1800 ft.^{3}

Referring to the conversion table appended to the Basic Mathematics note that we multiply cubic feet by 6.23 to obtain Imperial gallons.

$$1800 \text{ ft.}^3 \times 6.23 \text{ gal/ft}^3 = 11{,}214 \text{ Imperial Gallons}$$

time = 1 hour + 30 minutes
= 60 minutes + 30 minutes = 90 minutes

$$Q = \frac{V}{t} = \frac{11{,}214 \text{ I.G.}}{90 \text{ min.}} = 124.6 \text{ I.G./min.}$$

(3) Sewage is entering a plant at the rate of 10 MIGD. What is the velocity in cubic feet per second through a grit channel which is 3 feet wide and 4 feet deep?

$Q = v \times A$

v is the unknown quantity therefore it is isolated

$$v = \frac{Q}{A}$$

To obtain the flow in cubic feet per second multiply MIGD by 1.85.

$$Q = 10 \text{ MIGD} = 10 \times 1.85 \text{ cfs} = 18.5 \text{ cfs}$$
$$A = 3 \text{ ft.} \times 4 \text{ ft.} = 12 \text{ ft.}^2$$
$$v = \frac{18.5 \text{ ft.}^3/\text{sec.}}{12 \text{ ft.}^2} = 1.54 \text{ ft./sec.}$$

(4) Chlorination problems

A gas chlorinator is set to feed chlorine at 200 lb./24 hr. at a flow of 2 MIGD. The chlorine residual is 0.3 ppm. Find the chlorine demand.

Chlorine demand (ppm) = Chlorine applied (ppm) - Chlorine residual (ppm)

1 Imperial gallon of sewage = 10 lb.

$$\text{Chlorine applied} = \frac{200 \text{ lb.}}{20{,}000{,}000 \text{ lb}} = \frac{10 \text{ lb.}}{1{,}000{,}000 \text{ lb.}}$$
$$= \frac{10 \text{ lb.}}{1{,}000{,}000 \text{ lb.}} = 10 \text{ ppm}$$
$$\text{Chlorine demand} = 10 \text{ ppm} - 0.3 \text{ ppm} = 9.7 \text{ ppm}$$

(5) What would the chlorine feed rate have to be in the preceding example so that the chlorine residual would be 0.5 ppm?

chlorine applied = chlorine demand + chlorine residual

$$= 9.7 \text{ ppm} + 0.5 \text{ ppm}$$
$$= 10.2 \text{ ppm}$$

$$\text{chlorinator setting} = \frac{10.2 \text{ lb.}}{1{,}000{,}000 \text{ lb.}} \times \frac{20{,}000{,}000 \text{ lb.}}{24 \text{ hr.}}$$

$$= 204 \text{ lb.}/24 \text{ hr.}$$

(6) Primary Treatment

The primary settling tank at a plant serving 5,000 persons is 40 ft. long, 18 ft. wide and has a depth of 8 ft. 3 in. The daily average dry weather flow is 500,000 U.S. gallons. The length of the overflow weir is 50 ft.

Determine

A. The wetted surface area of the tank
B. The volume of the tank in U.S. gallons
C. The detention time in hours
D. The surface settling rate
E. The weir overflow rate

A. Area of tank

40 ft. x 18 ft. = 720 sq. ft.

B. Volume of tank

Volume = length x width x depth
Volume = 40 ft. x 18 ft. x 8.25 ft. = 5,940 cu.ft.

$$5{,}940 \text{ cu. ft.} \times 7.5 \frac{\text{gal.}}{\text{cu.ft.}} = 44{,}500 \text{ U.S. gal.}$$

C. Detention time

$$\text{Detention time (hr.)} = \frac{\text{Volume of tank in gal.}}{\text{flow in gal./day}} \times \frac{24 \text{ hr.}}{\text{day}}$$

$$= \frac{44{,}500 \text{ gal.} \times 24 \text{ hr./day}}{500{,}000 \text{ gal./day}}$$

$$= 2.1 \text{ hr.} = 2 \text{ hr.} + 0.1 \times 60 \text{ min.}$$
$$= 2 \text{ hr. } 6 \text{ min.}$$

D. Surface settling rate

This rate is generally expressed in gallons per day per square foot.

$$\text{Surface settling rate} = \frac{\text{Flow (gal./day)}}{\text{Surface Area (sq.ft.)}}$$

$$= \frac{500{,}000 \text{ gal./day}}{40 \text{ ft.} \times 18 \text{ ft.}}$$

$$= 694 \text{ gpd/sq. ft.}$$

E. Weir overflow rate

$$\text{Weir overflow rate (gpd per linear foot)} = \frac{\text{Flow (gal./day)}}{\text{total effective weir length (ft.)}}$$

$$= \frac{500{,}000 \text{ gal./day}}{50 \text{ ft.}}$$

$$= 10{,}000 \text{ gpd/linear ft.}$$

(7) The raw sewage entering a primary settling tank contained 250 mg/l of suspended solids. The primary tank effluent contained 110 mg/l of suspended solids. The average daily flow was 0.5 MIGD.

A. Calculate the pounds of solids removed by settling in one day.

B. Calculate the percent reduction of suspended solids by the primary treatment process.

C. Determine the total volume of the sludge in gallons if the moisture content was 95.5% (by weight).

A. Concentration of solids removed
$= 250\ mg/l - 110\ mg/l = 140\ mg/l$
Weight of sewage treated in one day
$= 0.5 \text{ million gal.} \times \frac{10\ lb.}{gal.} = 5{,}000{,}000\ lb.$

$$\text{Solids removed} = \frac{140\ lb.}{1{,}000{,}000\ lb.} \times 5{,}000{,}000\ lb.$$

$$= 700\ lb.$$

B. Percent efficiency =

$$\frac{\text{(solids in influent (ppm) - solids in effluent (ppm)}}{\text{solids in influent (ppm)}} \times 100$$

$$= \frac{(250\ ppm - 110\ ppm)}{250\ ppm} \times 100 = 56.0\%$$

C. Volume of sludge

The sludge is composed of 95.5% moisture; therefore, it must contain (100% - 95.5%) 4.5% solids.

4.5% of the sludge contents removed in one day weigh 700 lb. We wish to determine the weight (x) of 100%.

By ratio and proportion:

$$\frac{4.5}{100} = \frac{700\ lb}{x}$$

$$x = \frac{700}{4.5} \times 100 = 15{,}555\ lb./day$$

1 gallon of sludge = 10 lb.

$$\frac{15{,}555\ lb./day}{10\ lb./gal.} = 1{,}555 \text{ gal. of sludge/day}$$

Rectangle:

The area, A, of a rectangle is equal to the product of its length and its width.

$A = lw$

Square:

The area, A, of a square is equal to the square of one of its sides.

Perimeter: The perimeter, P, of a square may be found by multiplying the length of one side by four.

$A = s^2$

$P = 4s$

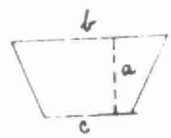
Parallelogram:

The area, A, of a parallelogram is equal to the product of its base and altitude.

$A = ba$

Trapezoid:

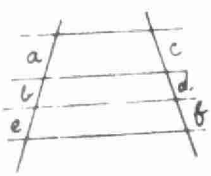
The area, A, of a trapezoid is equal to one-half the sum of its base and top multiplied by its height.



$A = \frac{1}{2}(b + c)a$

Lines:

Any two lines cut by three or more parallel lines are divided into proportional segments.



$a : b = c : d$

$b : e = d : f$

Triangle:

The area, A, of a triangle is equal to one half the product of its base and its altitude.

$A = \frac{1}{2} ba$

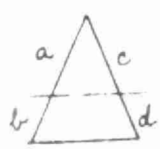
$A = \sqrt{s(s - a)(s - b)(s - c)}$

Where $s = \frac{1}{2}(a + b + c)$

The square of the hypotenuse is equal to the sum of the squares of the other two sides for any right triangle.

$a^2 + b^2 = c^2$

A line parallel to the base of a triangle divides the other two sides proportionally.



$a : b = c : d$

$(a + b) : b = (c + d) : d$

$(a + b) : a = (c + d) : c$

The perimeter, P, of an *isosceles triangle* may be found by doubling the length of one of its equal sides, a, and adding the length of the base.

$P = 2a + b$

Areas and Volumes of Plane and Solid Geometrical Figures

Circle:

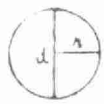
The area, A, of a circle is equal to π multiplied by the radius squared, or by one fourth the diameter squared.

$$A = \pi r^2 \text{ or } \frac{\pi d^2}{4}$$

Sphere:

The area, A, of a sphere equals the product of 4π and the radius squared.

$$A = 4\pi r^2$$



The volume, V, of a sphere is equal to $\frac{\pi}{6}$ times the diameter cubed.

$$V = \frac{\pi}{6} d^3$$

Cylinder:

The lateral area, A, of a cylinder equals 2π times the product of its radius and height, L.

$$A = 2\pi r L$$

The volume, V, of a cylinder equals π times the product of the radius squared and the height.

$$V = \pi r^2 L \text{ or } \frac{\pi d^2}{4} L$$

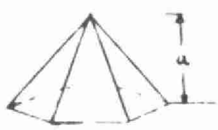
Cone:

The volume, V, of a cone equals one-third π times the radius squared times the height.

$$V = \frac{\pi}{3} r^2 a \text{ or } \frac{\pi}{12} d^2 a$$

Pyramid:

The volume, V, of a pyramid equals ⅓ times the area of the base multiplied by the height, a.



$$V = \tfrac{1}{3} (\text{area of base}) a$$

Frustum of Cone or Pyramid:

The volume, V, of the frustum of a cone or pyramid equals ⅓ height, a, times $A_1 + A_2 + \sqrt{A_1 A_2}$ where A_1 and A_2 are the area of the base and top.

$$V = \frac{a}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

Parallelepiped:

The volume, V, of a parallelepiped (rectangular solid) such as a cube or rectangular basin may be found by multiplying its length by its width by its height.

$$V = abc$$

AVERAGES AND MEANS

Arithmetic Mean

An average is a single number used to represent a series of measurements or other group of data. The most commonly used average is the arithmetic mean. To find the arithmetic mean the values of the individual results are added and the sum is divided by the number of results originally listed.

Example 1. The following dates indicate BOD results of samples collected of the effluent from a sewage treatment plant. Calculate the average result or arithmetic mean.

Date	BOD in PPM
January 7	17
February 12	12
March 4	18
April 6	21
May 2	16
June 5	15

Add the BOD's listed and divide by the number of results listed (6).

$$\text{Arithmetic Mean} = \frac{17+12+18+21+16+15}{6} = \frac{99}{6} = 16.5 \text{ ppm}$$

Recalling the presentation on significant figures the answer is expressed to 2 significant figures. Answer: 17 ppm

Weighted Averages

If a unit operates at a constant rate for a period of time, then changes its rate for another unit of time, etc., its average rate of output can be expressed by calculating its weighted average.

Example 1. In the following table the rate of pumping is constant; beginning on the hour and continuing until the next recorded hour. Calculate its weighted average according to its entire time of operation i.e. 24 hours.

Hour	GPM
12 - Noon	200
2 p.m.	300
5 p.m.	150
7 p.m.	400
10 p.m.	200
4 a.m.	150
6 a.m.	250
9 a.m.	350
12 - Noon	-

Each rate is weighted according to the hours operated at the corresponding rate.

Hours	x	Rate (gpm)	=	Weighted Rate
2	x	200	=	400
3	x	300	=	900
2	x	150	=	300
3	x	400	=	1200
6	x	200	=	1200
2	x	150	=	300
3	x	250	=	750
3	x	350	=	1050
24				6100

$$\text{Weighted average} = \frac{6100}{24} = 254.2$$

Answer: 254 gpm

The Median

Another method of expressing the average representative figure is by determining the median. This value is found by arranging the numbers in descending order and selecting the midway value. If there are two outstanding numbers at the half-way mark, the arithmetic average of these two numbers is

taken. Therefore, half of the values are greater and half of the values are smaller than the median. The advantage of this method of averaging results is that it is not affected by abnormally large or small values in a set of results.

Example 1. The following list tabulates the bacteriological results of water samples collected from a particular lake in Ontario. Determine the median of these results which will be representative of the bacteriological quality of the lake. The results in total coliforms per 100 ml are; 2,000,000, 7,000, 4,000, 200,000, 1,500, 900, 40,000, 700. The numbers are listed in descending order:

~~2,000,000~~
~~200,000~~
~~40,000~~
7,000
4,000
~~1,500~~
~~900~~
~~700~~

7,000 and 4,000 are midway down the scale of results. The arithmetic mean of these two numbers is $\frac{7,000+4,000}{2}$

$= 5,500$

Answer: the median is 5,500 Total Coliforms per 100 ml of sample

The Mode

Another representative value is the mode. The mode is that number which in any series of observations occurs more often than any other. Its chief use in sanitary engineering problems is also related to coliform density representations.

Example 1. What is the mode in the following set of numbers; 400, 25, 50, 70, 25, 200, 25, 10 and 5. 25 appears more than any other number, therefore, it is the mode.

Answer: 25

OTHER MATHEMATICAL EXAMPLES

Population Equivalent

It is common in design considerations to assume that each person on the sewer system will contribute 0.17 lb of Biochemical Oxygen Demand (BOD) per day and 0.20 lb of Suspended Solids (SS) per day. These equivalents are often used to convert total pounds of solids or BOD from industrial establishments to equivalent population.

Example 1. An industry discharges 340 lb of BOD per day to a sewage collector system. Calculate the population equivalent of this pollution load.

The population equivalent for BOD is 0.17 lb/day

$$\text{Population Equivalent} = \frac{340 \text{ lb/day}}{0.17 \text{ lb/day/person}} = 2000 \text{ persons}$$

Example 2. If a sewage waste discharges 8460 lb of SS per day to a sewage treatment plant, determine its population equivalent.

The population equivalent for SS is 0.20 lb/day

$$\text{Population Equivalent} = \frac{8460 \text{ lb/day}}{0.20 \text{ lb/day/person}} = 42{,}300 \text{ persons}$$

The population equivalents listed above may require some modifications depending on the proposed conditions. For example, some municipalities may allow homes to install garbage grinders which discharge the wastes to the sanitary sewer system. Full use of garbage grinders in a community increases the SS up to 100% with an average of about 60% and increases the BOD up to 65% with an average of 30%. The effect on the volume of sewage is negligible.

Activated Sludge Process

Example 1. The following pertinent data are noted for a typical activated sludge plant.

2-primary settling tanks each 52' x 16' x 10' water dimensions (W.D.) with four full width weirs at the effluent end.

4 aeration tanks each 72' x 18' x 10' W.D.

2-blowers each at 850 ft^3/min.

2-final settling tanks each 56' x 16' x 10' W.D.

1 chlorine contact tank 37' x 12' x 7' W.D.

1 digester 52' diameter (Ø) x 24' W.D.

The results of flow studies and samples indicate:

Flow:	1,000,000 gallons daily
Raw BOD:	200 ppm
Primary BOD:	130 ppm
Final BOD:	15 ppm
Raw Suspended Solids:	250 ppm
Primary Suspended Solids	100 ppm
Final Suspended Solids:	15 ppm
Raw Sludge:	3% Solids
Raw Sludge:	70% Volatile
Digested Sludge:	10% Solids

(The British system of units is used in all measurements)

Determine the following:

(1) Detention time in primary tanks

(2) Weir overflow rate in I.gal/ft/day in primary tank

(3) Air supply in ft^3/gal of sewage

(4) Detention time in aeration tank with 25% return of activated sludge

(5) Percent removal of BOD

(6) Percent removal of Suspended Solids

(7) Detention time in chlorine contact tank

(8) Pounds of BOD removed

(9) Pounds of Suspended Solids removed

(10) Gallons of sludge pumped

(11) Pounds of volatile solids to digester

(12) Cubic feet of digester space per pound of volatile solids added

(13) Gallons of digested sludge to be removed each day

- Round off answers to significant figures -

Answer:

Primary Tank Volume $= 2(52' \times 16' \times 10') = 16{,}640\ ft^3$

$= 16{,}640\ ft^3 \times \dfrac{6.25\ gal}{ft^3}$

$= 104{,}000\ gal$

(1) Detention time $= \dfrac{104{,}000\ gal}{\dfrac{1{,}000{,}000\ gal}{24\ hr}} = 0.104 \times 24\ hr = 2.5\ hr$

(2) Length of weirs $2(16' \times 4) = 128'$

Overflow rate $= \dfrac{1{,}000{,}000\ gal/day}{128\ ft} = 7{,}800\ gal/ft/day$

(3) Volume of air $= 2(850\ \dfrac{ft^3}{min} \times \dfrac{60\ min}{hr} \times \dfrac{24\ hr}{day})$

$= 2{,}450{,}000\ ft^3\ /day$

Air supply $= \dfrac{2{,}450{,}000\ ft^3\ /day}{1{,}000{,}000\ gal/day} = 2.45\ ft^3\ /gal$

(4) Volume of aeration tanks $4(72' \times 18' \times 10')$

$= 5200\ ft^3 \times \dfrac{6.25\ gal}{ft^3} = 324{,}000\ gal$

Detention time $= \dfrac{324{,}000\ gal}{1{,}250{,}000\ gal/24\ hr} = 0.26 \times 24\ hr$

$= 6.2\ hr$

(5) % BOD removed $= \dfrac{200 - 15}{200} \times 100 = 92.5\%$

(6) % Suspended Solids removed $= \dfrac{250 - 15}{250} \times 100 = 94.0\%$

(7) Volume chlorine contact tank $= 37' \times 12' \times 7' = 3100\ ft^3$

$= 3100\ ft^3 \times \dfrac{6.25\ gal}{ft^3}$

$= 19{,}500\ gal$

Detention time $= \dfrac{19{,}500\ gal}{1{,}000{,}000\ gal/24\ hr} = 0.0195 \times 24\ hr$

$= 0.47\ hr$

$= 0.47\ hr \times \dfrac{60\ min}{hr} = 28.2\ min$

(8) Pounds of BOD arriving $= 1{,}000{,}000\ \dfrac{gal}{day} \times \dfrac{10\ lb}{gal} \times \dfrac{200\ lb}{1{,}000{,}000\ lb}$

$= 2{,}000\ lb/day$

Pounds of BOD leaving $= 1{,}000{,}000\ \dfrac{gal}{day} \times \dfrac{10\ lb}{gal} \times \dfrac{15\ lb}{1{,}000{,}000\ lb}$

$= 150\ lb/day$

Pounds of BOD removed $= 2000\ \dfrac{lb}{day} - \dfrac{150\ lb/day}{day} = 1850\ lb/day$

(9) Pounds of Suspended Solids arriving

$= 1{,}000{,}000\ \dfrac{gal}{day} \times \dfrac{10\ lb}{gal} \times \dfrac{250\ lb}{1{,}000{,}000\ lb} = 2500\ lb/day$

Pounds of Suspended Solids leaving

$= 1{,}000{,}000\ \dfrac{gal}{day} \times \dfrac{10\ lb}{gal} \times \dfrac{15\ lb}{1{,}000{,}000\ lb} = 150\ lb/day$

Pounds of Suspended Solids removed

$= 2500\ lb/day - 150\ lb/day = 2350\ lb/day$

(10) 2350 lb/day of Suspended Solids removed
raw sludge is 3% Suspended Solids

$\therefore$ 3% of raw sludge $= 2350\ lb$

100% of raw sludge $= \dfrac{2350}{3} \times 100 = 78{,}333\ lb = 7{,}833\ gal$

$\therefore$ amount of raw sludge pumped to digester $= 7{,}833\ gal$

(11) Raw sludge is 70% volatile

$\therefore$ $2350 \times \frac{70}{100}$ = 1645 lb of volatile solids to digester

(12) Volume of digester $= \pi \times \frac{52^2}{4} \times 24 = 51{,}000\ ft^3$

Digester loading $= \frac{51{,}000\ ft^3}{1645\ lb/day} = 31\ ft^3/lb$ volatile solids added/day

(13) 7833 gallons of raw sludge containing 3% dry solids is pumped to the digester each day.

Volume occupied by dry solids $= \frac{3}{100} \times 7833 = 235$ gal

The same volume will be occupied by the dry solids whether the moisture is increased or decreased.

Digested sludge contains 10% dry solids.
10% digested dry solids occupy 235 gal.
100% digested dry solids occupy 2350 gal.
An average of 2350 gallons of digested sludge will have to be pumped from the digester each day.

Example 2. 5000 lb dry weight of sludge enters a plant per day and 60% is removed. A sludge pump discharges at a rate of 100 gpm and the sludge contains 5% solids. Find the volume of sludge and the length of time required to pump the sludge removed.

Dry wt. of sludge removed $= \frac{60}{100} \times 5000 = 3000$ lb

5% of wet sludge weighs 3000 lb
1% of wet sludge weighs 600 lb
100% of wet sludge weighs $600 \times 100 = 60{,}000$ lb

Volume of wet sludge $= 60{,}000\ lb \times \frac{1\ gal}{6.25\ lb}$
$= 9600$ gal

Time of pumping $= \frac{9600\ gal}{100\ gal/min} = 96$ minutes

Example 3. 1000 ft^3 of digested sludge containing 95% moisture is dewatered so that it contains 90% moisture. What volume does the sludge now occupy? What would the volume be if the sludge were dewatered to 50% moisture?
The specific gravity of dry solids and of sludge are both assumed to be 1.0.

Volume occupied by dry solids (at 5%)
$= 0.05 \times 1000 = 50\ ft^3$

The same volume would be occupied by dry solids whether the moisture content is increased or decreased. When moisture = 90%, dry solids = 10%

If 10% of total volume = 50 ft^3
100% or total volume = 500 ft^3

That is, sludge with 90% moisture only occupies 500 ft^3;
whereas, 95% moisture sludge occupies 1000 ft^3

When moisture = 50%, dry solids = 50%

If 50% of total volume = 50 ft^3
100% or total volume = 100 ft^3
That is, sludge with 50% moisture only occupies 100 ft^3

Example 4. A digester produces 10,000 ft^3 of gas per day. Raw sludge is added at the rate of 5000 gal per day. The raw sludge is 6% solids and is 65% volatile. How many ft^3 of gas are produced per pound of volatile solids added?

5000 gal of sludge per day = 50,000 lb

Weight of solids added per day = 0.06 x 50,000 lb
= 3000 lb

Weight of volatile solids added per day
= 0.65 x 3000 lb
= 1950 lb

Gas produced per lb of volatile solids added
$= \frac{10{,}000}{1950} = 5.1\ ft^3$

Effect of Effluent on the Stream Water Quality

Example 1. A sewer containing 100 ppm BOD discharges into a stream at a rate of 700,000 g/d. Flow in the stream is 20 cfs and the BOD of the stream upstream of the effluent is 2 ppm. What is the theoretical BOD of the mixture below the point of discharge?

BOD of mixture in lb = BOD in lb of effluent + BOD in lb of stream.

$$\text{BOD of effluent} = 700{,}000\ \text{g/d} \times 10\ \text{lb/g} \times \frac{100\ \text{lb}}{1{,}000{,}000\ \text{lb}}$$

$$700\ \text{lb/day}$$

$$\text{BOD in stream} = 20\ \text{cfs} \times \frac{1{,}000{,}000\ \text{g/d}}{1.85\ \text{cfs}} \times 10\ \text{lb/g} \times \frac{2\ \text{lb}}{1{,}000{,}000\ \text{lb}}$$

$$= 216\ \text{lb/day}$$

$$\text{BOD in mixture} = 700\ \text{lb} + 216\ \text{lb} = 916\ \text{lb}$$

Concentration of BOD in mixture =

$$\frac{916\ \text{lb/d}}{20\ \text{cfs} \times \frac{1{,}000{,}000\ \text{g/d}}{1.85\ \text{cfs}} \times 10\ \text{lb/g}}$$

$$= \frac{8.5\ \text{lb}}{1{,}000{,}000\ \text{lb}}$$

$$= 8.5\ \text{ppm}$$

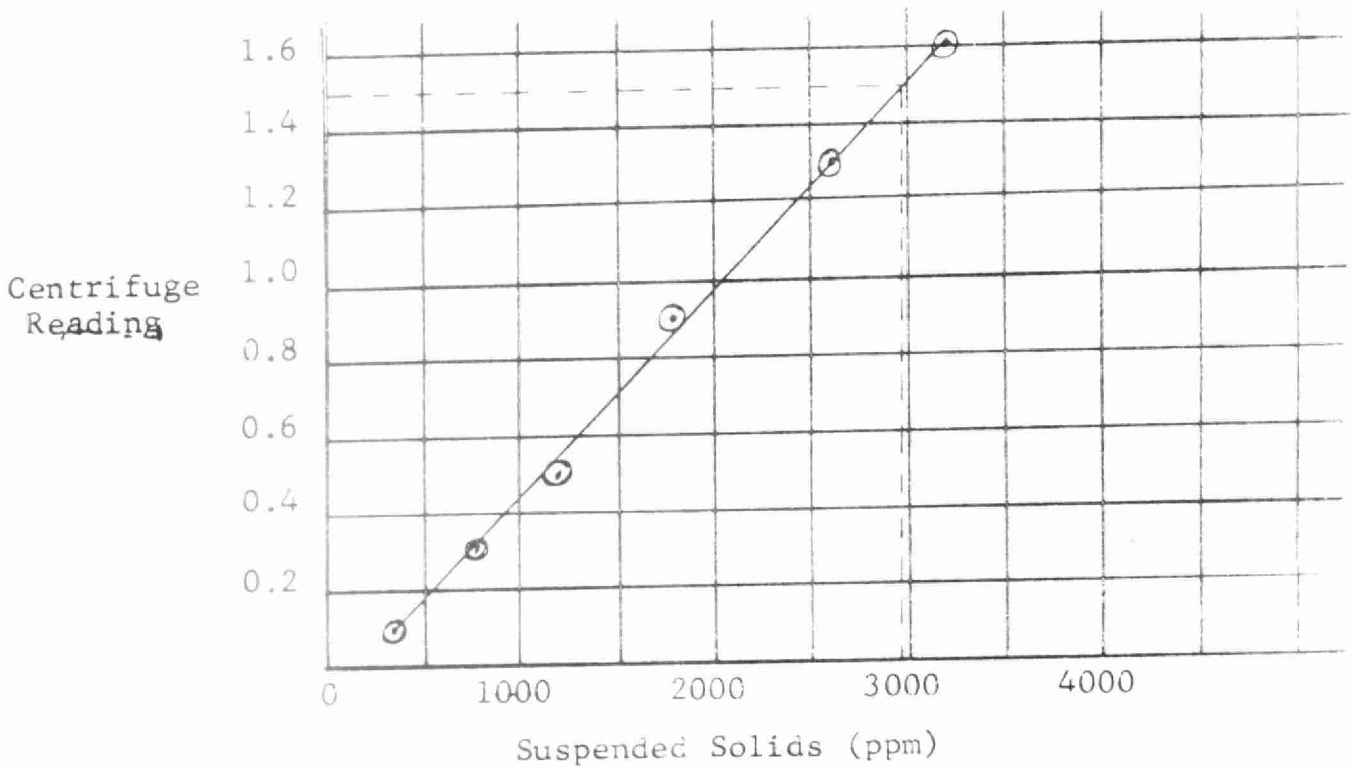
Graphical Representation

A centrifuge reading - suspended solids relationship was required at an activated sludge sewage treatment plant. The samples were prepared in the prescribed manner for centrifuging and analysis for suspended solids (SS) content.

The following values indicate the respective results. Prepare the required reference graph for SS content indication based on the centrifuge reading.

Centrifuge Reading	Suspended Solids (ppm)
0.1	310
0.3	740
0.5	1150
0.9	1800
1.3	2600
1.6	3200

If the centrifuge reading at the plant is 1.5 what is the SS content in the aeration tank?



Answer: 2950 ppm

CONCLUSION

This lecture series was intended to expose the student to some typical calculations involving the sewage treatment process. Hopefully, it stimulated some interest in the proper direction to enable him to carry out these and other similar computations at his plant. The effectiveness and efficiency of the various treatment units should be regularly assessed and the results should be maintained on file for comparison at a later date.

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 12

EQUIPMENT MAINTENANCE

SYSTEM

OBJECTIVES:

Trainee will be able to:

1. List the components that a good maintenance programme requires.
2. List the diagrams essential to proper maintenance of equipment; explain what these diagrams should show and know how each part or piece of equipment functions within the process.
3. Outline the usefulness of a data card.
4. Determine the frequency of inspection.
5. Outline the frequency maintenance card system.
6. State why it is necessary to note checks on the frequency cards.
7. Determine the checks and preventive maintenance to be done at any time.
8. Give an example of frequency control.
9. State why a master schedule and board are necessary.
10. Name 4 predictive tests.
11. State what should be recorded in a log book.
12. Name 4 pieces of information which can be obtained from a log book.

EQUIPMENT MAINTENANCE SYSTEM

The public demands and expects high quality water and sewage services which operate without interruption. To achieve this objective, the plant equipment must be maintained in good working condition at all times.

Good maintenance of equipment provides effective and efficient operation and cuts down on expensive breakdowns and manpower requirements.

A GOOD MAINTENANCE PROGRAMME REQUIRES:

1. *definition of the types of maintenance for accounting purposes*
2. *knowledge of the process and equipment*
3. *data cards for parts and project information*
4. *frequency maintenance routines to ensure consistent inspection procedures*
5. *a recording system for evaluation of the programme and equipment*

Preventive Maintenance

Preventive maintenance is regularly scheduled maintenance,checks and tests carried out to prevent unexpected or untimely breakdowns of equipment. This reduces costly breakdowns, permits prediction of breakdown time to optimise the time between overhauls, and ensures continuous service. Also included under this heading are equipment modifications.

Breakdown Maintenance

When a piece of equipment fails, breakdown maintenance is needed to restore it to operation.

Routine Maintenance

This consists of daily lubrications, temperature checks, and all other short time maintenance routines which cannot readily be classified. It includes the work performed under the standing daily maintenance routines.

By applying and dividing a programme into three *categories* the maintenance carried out can be accounted for and evaluated over a period of time to determine its effectiveness.

Process & Equipment

Complete diagrams of the plant process, electrical distribution, control panels, and the instrumentation diagrams must be available. These diagrams should show the *continuity* of the process, electrical system and controls, and their *interdependency.* It is necessary to know what *purpose* each part (or piece of equipment) performs, *how it works,* and *how it is expected to perform under ideal conditions.* In addition, the operations personnel must know *what happens to the process if any part fails,* and on failure, *what alternatives exist to keep the system operational.*

THE PREVENTIVE MAINTENANCE SYSTEM

Data Cards (Figure 12-1)

Data cards are the *inventory of major equipment.* They are often tedious to fill out but the information

must be correct and complete. Data cards should include information on pump impellers, for example. Data cards enable such *parts* as bearings to be purchased before disassembling a piece of equipment.

Use data cards that can easily be filed in a file-box similar to that shown in Figure 12-4.

Equipment Numbers

The equipment components in a plant should be numbered for easy identification and to simplify recording of data. Any numbering system, as long as it is consistent, may be used. Perhaps the most simple system is one which uses #1 sewage pump, #3 low lift pump, etc.

Frequency of Maintenance

To determine the frequency of inspections and maintenance, use the *manufacturer's guidelines* and *previous experience* as an initial guide. When the system has been used for one or two years, an *analysis of the maintenance system results* will indicate whether the inspection frequency is sufficient, or whether it should be changed. The maintenance programme must be *tailored to meet the needs of any plant.*

Maintenance periods are usually divided into *monthly, 3-monthly, semi-annual and annual categories. Daily and weekly* (which are associated with the daily) checks, etc., are also required. This daily type of maintenance may only take a total of an hour or so each day on a number of pieces of equipment. *A daily work standing order card* is sufficient, incorporating any

EQUIPMENT DATA			EQPT. No.
PROJECT			EQPT. No.
EQUIPMENT TITLE			EQPT. No.
MAKE			EQPT. No.
MODEL	SERIAL No.	RPM	HORIZ./VERT
TRANSMISSION		SIZE/CAP.	
		IMPELLER DIA.	
BEARINGS		SHAFT DIA.	
SEALS			
MOTOR MAKE			
H.P.	AMPS	VOLTS	SERIAL No.
RPM	TYPE	CODE	FRAME
DUTY	TEMP	DESIGN	S.F.
BEARINGS			
MOTOR CONTROLS			
HEATERS			

Figure 12-1 DATA CARD (FRONT)

EQUIPMENT DATA

Figure 12-1 DATA CARD (BACK USED FOR ADDITIONAL INFORMATION AND SPARE PARTS INFORMATION.)

FINAL TANK #3 GEAR UNIT 08-19-05-1C-03 PROJECT:

Worm Gear - Recommended Oil

0 - 40^{o}F. AGMA 5EP Shell Macomo 72 or equal

30 - 125^{o}F. AGMA 8EP Shell Macomo 978 - 82 or equal

1. Check all mounting bolts and nuts are secured.
2. Check alignment.
3. Check for any signs of increased vibration.

Typical Frequency Maintenance (or Depth) Card (Front)

Figure 12-2

MAINTENANCE PERFORMED AS SPECIFIED

DATE	BY	DATE	BY	DATE	BY

Figure 12-3 Typical Frequency Maintenance Card (Back)

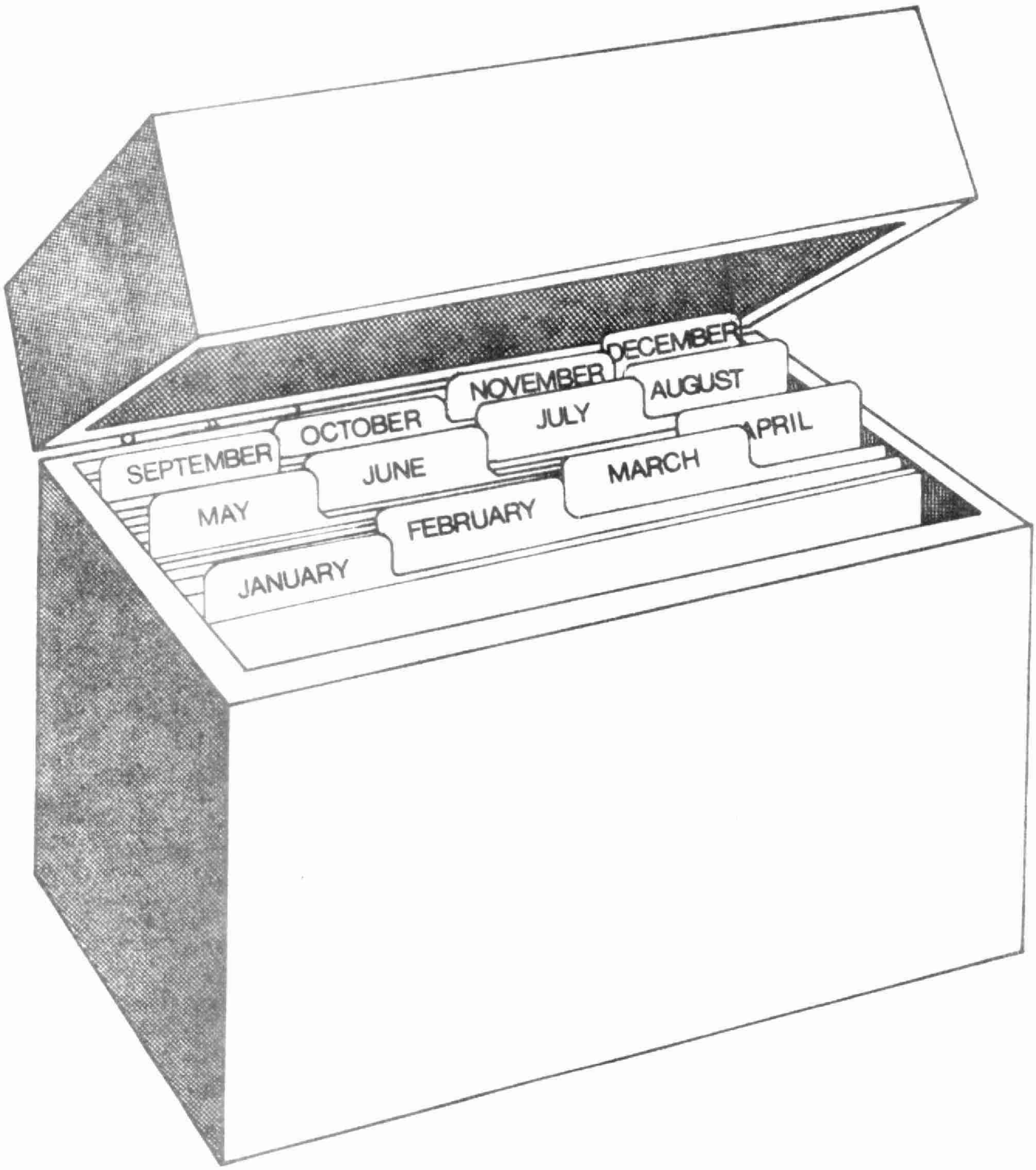


Figure 12-4 **FILE BOX**

weekly maintenance, the total time being allotted to the routine maintenance category.

The monthly, 3-monthly, semi-annual and annual maintenance may require one, two, or more man hours per piece of equipment and must be controlled separately with time allotted for each piece of equipment. *Coloured cards* (Figures 12-2 and 12-3) are used to denote the *frequency of maintenance:*

blue - monthly

green - 3-monthly

orange - 6-monthly

yellow - annually

Prepare such cards for equipment, and *stagger them throughout different months of the year.* This makes a fairly even work load available to the work force in any particular month. *A small file box* and *indexed month cards* (January, February, etc.) make this a very simple reminder system (Figure 12-4).

The coloured frequency maintenance cards have the *equipment name, number and project* noted on the front. The front of the cards also shows the *"checks"* to be made and includes the lubrication instructions (if any). The colour denotes the frequency of maintenance.

The *"checks"* will ensure *consistency of inspection.* Listing the checks and work to be completed ensures that *all knowledge is not vested in one person*

and, in the case of absence or termination, another person can step in to do the necessary work. The list also helps in *supervising the system.* A person with a check list is more apt to carry out the checks and not just indicate, without actually doing the checks, that the inspection was completed.

Inserting the work to be done on the frequency maintenance (depth) cards is a task which must be done well for a successful preventive maintenance programme. This provides a *consistent preventive maintenance package.* Maintenance noted on a card such as "inspect, repair and comment" is vague and can lead only to inconsistency and poor maintenance. *Maintenance manuals must be read* and *thoroughly understood, experience drawn on,* and the necessary maintenance details briefly outlined on the cards.

As an example of frequency control, in the month of July one may find three orange cards for motors, three green cards for pumps (3-month check), three orange cards for electrics (6-month check), a blue card for aeration equipment (monthly check) and a yellow card for a boiler (annual check). At the beginning of the month, these cards are taken out of the file box, put in a monthly work holder of some type, and the work scheduled for July. When work is completed the back of the card is initialled and dated, and the card returned

to the file box according to its frequency (the green cards would be put under the month of October, the orange cards under the month of January, etc.)

A master schedule (Figure 12-5) should show equipment and when preventive maintenance work is required. It gives an *overall picture* of the system and provides an *easy check that cards are in the correct rotation order* for supervision of that programme.

Posting a preventive maintenance system on a board similar to that of the master schedule, with coloured pins to show the different frequency work loads and which equipment requires inspection in each month, provides the operations/maintenance personnel with an *overview of the preventive maintenance scheme and frequencies.* The *visiting public* can learn from the board how the municipality is trying to protect their environment and at the same time provide continuity of service.

Predictive Tests

Record load checks such as: *voltage, current, megger tests, vibration readings, bearing shock pulse tests, temperature indications,* etc., to *show any trend.* For example:

a) is the current reading consistent?

b) is the temperature reading increasing?

These are the *predictive tests* of the preventive maintenance system used to determine any deterioration in results.

EQUIPMENT	EQUIPT No.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
COMMINUTOR		●	●	●	◓	●	●	●	●	●	◓	●	●
COMMINUTOR - MOTOR		●	●	●	◓	●	●	●	●	●	◓	●	●
No. 1 RAW SEWAGE PUMP				◓			○			◓			○
No. 1 MOTOR				○			○			○			○
No. 1 VALVES				○			○			○			○
No. 2 RAW SEWAGE PUMP				◓			○			◓			○
No. 2 MOTOR				○			○			○			○
No. 2 VALVES				○			○			○			○
RETURN PUMP - V.S.		●	●	◓	●	●	●	●	●	◓	●	●	●
PUMP MOTOR				○			○			○			○
PUMP VALVES				○			○			○			○
REEVES DRIVE		●	●	◓	●	●	●	●	●	◓	●	●	●
RETURN PUMP - C.S.				◓						◓			
PUMP MOTOR				○			○			○			○
PUMP VALVES				○			○			○			○
SLUDGE PUMP		●	●	●	●	◓	●	●	●	●	●	◓	●
PUMP MOTOR			○			○			○			○	
PUMP VALVES			○			○			○			○	
SLUDGE PUMP-REDUCT						◓						◓	
SUMP PUMP				◓						◓			
CHLORINATOR						◓						◑	
CHLORINE LINES						◓						◑	
FLOW METER					◑								
EXHAUST FAN (CHLOR)							◑						
CHLORINE SCALE												◑	
BOILER										◑			
MOTOR CONTROLS							◑						
FINAL CLARIFIER		●	●	●	◓	●	●	●	●	●	◓	●	●
CLARIFIER MOTOR		○			○			○			○		
CLARIFIER REDUCER		○			◓			○			◓		

PREVENTIVE MAINTENANCE BOARD

LEGEND: ● – 1 MONTH ○ – 3 MONTHS ◓ – 6 MONTHS ◑ – ANNUAL

Master Schedule

Figure 12-5

In-Plant Recording (Figure 12-6)

Records should be kept in a ring binder *log book. Each piece of equipment has a separate page* in this book, with the following information recorded:

a) work done

b) time spent

c) costs for any piece of equipment

The accuracy, usefulness and reliability of the maintenance system depend upon the conscientious completion of this log book.

Information which can be obtained from records in a log book:

a) comparison of existing equipment

b) major faults and problems

c) evaluation of the maintenance system

d) evaluation of maintenance and reliability of equipment as a basis for selection of future equipment.

e) evaluation and comparison of maintenance costs for equipment

f) measures of performance and effectiveness of equipment and maintenance

g) information for discussions with suppliers and the provision of "feedback".

Any preventive maintenance system is only a part of the overall maintenance function; its application must be reviewed with this in mind. *An evaluation of the*

Equipment Name :
Equipment Number:

DATE		WORK DONE, MATERIALS & CATEGORY	MAN HOURS	CONTRACTOR, COST	LABOR TOTAL	MATERIAL COST	MATERIAL TOTAL

Figure 12-6 Typical Log-Book Page

success or deficiencies of the preventive maintenance scheme can be obtained only if total maintenance data is recorded. The *costs* of preventive maintenance and breakdown maintenance must somehow be *minimized.* To achieve this, complete maintenance data must be available.

There is no magical mathematical formula to establish how much maintenance should be done. Whenever treatment is incomplete, the question to be asked is *"Was enough maintenance done to prevent equipment failure?"*

Not only does *poor service annoy the consumer* but all water and sewage operators and maintenance personnel have a *moral responsibility* to ensure that the total environment, water quality, and service is not impaired.

Good maintenance in water and sewage works is in the hands of the operators and maintenance personnel.

SUBJECT:

BASIC SEWAGE

TREATMENT OPERATION

TOPIC: 13

SAFETY

OBJECTIVES:

Trainee will be able to:

1. Name three (personal) hazards common to treatment plants.

2. List the safety rules to follow when working in:

   - the pumping stations
   - the lab
   - the treatment plant

3. List at least eleven precautions to take for electrical maintenance.

SAFETY PRACTICES IN SEWAGE WORKS

INTRODUCTION

The dangers associated with sewage works operation emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur at sewage plants and during sewer maintenance and although infrequent at any particular location, on a country-wide basis many such accidents occur. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsiblity of sewage works supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A, B, C" of accident prevention is "always be careful". However, one must learn how to be careful and what to avoid. With this knowledge one can then always think and practice safety.

HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These hazards may be as follows:

1. Body infections
2. Physical injuries
3. Dangers from noxious gases or vapours and oxygen deficiencies.

NO. 1 Body Infections

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.

2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.

3. A good policy is "never put your hands above your collar when working on plant equipment".

4. Always wear your rubber boots when working in tanks, washing down etc., don't wear your street shoes.

5. Don't wear your rubber boots or coveralls in your car or at home.

6. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses etc.

7. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.

8. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.

9. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.

Workers who come into contact with sewage are exposed to all the hazards of water-borne diseases, including Typhoid Fever, Amorbic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus innoculations are recommended. These may be obtained free of charge from local Health Officers.

Wearing Apparel

Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks etc.

Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.

Hard hats should be available and worn when working below ground level, i/e in open tanks etc., or in confined areas with low head room or during any construction on the plant site. Always wear safety goggles when grinding, chipping or scrapping and wire brushing old painted surfaces.

PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants should have first aid kits and as many of the plant personnel as possible should have "St. Johns Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having (5) five or more people working as a group on any shift one of them is required to hold a "St. Johns Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

In and Around the Plant

No Smoking Areas

Influent buildings

Detritor rooms

Wet and dry wells of plant pumping stations

Pump rooms containing raw sludge pumps

Tunnels having pipe galleries carrying digester gas or natural gas pipe

Digesters, digester buildings

Sewers, manholes

Sludge holding tanks (covered)

Near sludge thickening tanks while being mixed with compressed air

Sludge conditioning tanks in filter rooms

Sludge loading pipes to trucks

Sludge discharge pipes to drying beds

When working at the plant, observe the following common sense rules:-

Walkways must be kept clear of loose objects such as pails, shovels, loose rope, etc.

Grease and oil should be wiped up immediately, icy walks can be salted or sanded

All tools must be picked up, cleaned and returned to their storage area.

When it is necessary to use tools in an empty tank or manhole etc., they should be lowered in a pail on a rope and removed in the same way. Brooms and shovels can also be transported by rope. Do not attempt to climb up and down ladders with your hands full of tools

Don't overload yourself when using stairways, keep your load small enough to be able to see over it and have one hand free to use the hand rail

Do not attempt to climb up or down a ladder or over a railing while handling a hose under pressure

When washing down the floor of any tank, be sure you wear hip wader rubber boots with good treaded soles, do not wear rubber boots with worn soles and heels

When working in a narrow or confined passage where grit or sludge accumulates, wear the appropriate rubber clothing provided.

Always wear rubber or plastic-coated waterproof gloves when cleaning pumps, handling hoses, removing grit or sludge or loading sludge trucks, etc.

When it is necessary to use an extension ladder to enter any empty tank, use the collector arms in clarifiers for a backstop for the ladder legs. In an aeration tank, the ladder must be lashed. Entry with a ladder into the tank must be from a walkway (not from a narrow dividing wall) and in all cases the ladder should be lashed to a handrail

Whenever working below ground level (in tanks, manholes, etc.) or under scaffolding, hard hats shall be worn

Do not hang clothes on electrical disconnect handles, light switches or control panel knobs

Manhole covers and trap doors to wells must be replaced, and closed after using or protected by guard rails if it is necessary to leave open

The proper tool must be used when removing or replacing manhole covers. Do not attempt to move or close a manhole cover with your hands

When working in manholes located in a street or road, signs with blinking amber lights and red flags must be posted at each approach to the area

When removing grit from tanks or wet wells, do not pull up pails filled with grit by rope. Use an "A" frame and pulley or some other type of support with a pulley. The support and pulley must be fastened firmly to prevent it from toppling over during its use

When leaning out through the railings over any tank (or cleaning out spray nozzles, etc.) a safety belt with a short rope and a safety snap shall be used.

Mixing and Handling Chemicals

Ventilation system must be in operation when handling chemicals

Plastic safety goggles, and nose filter must be worn while handling hydrated lime (unloading, storing and mixing)

Plastic safety goggles and plastic-covered canvas gloves must be worn while mixing or handling liquid ferric chloride

Do not....

- Grease or oil or attempt to service any machinery while it is in operation. Pumps on automatic control must be locked out and key carried by the operator during servicing.
- Make any adjustments to operating machinery while alone. If it is necessary to run the unit to adjust it, a second man must be present and be beside the stop and go switch.
- Work around electrical panels, disconnects or switches alone. Enter any crawl space under flooring for any purpose until the area has been ventilated, a second man should be present.
- Service pumps and shafts in the dry wells of pumping stations, and in plants where the pumps and shafts are less than three feet apart, without shutting off all pumps and locking them out.
- Under any circumstances, attempt to grease or service pump shafting while standing on beams, piping, loose planks, guard rails, or by leaning out, over or through guard rails. If a ladder must be used, then a second man must be present to hold the ladder steady and for any other assistance required of him.

Pumping Stations

ITEMS REQUIRED

Fire Extinguisher

Signs: "START VENT BEFORE ENTERING"

"DANGER PUMPS ON AUTOMATIC TIMER"

"NO SMOKING"

"DANGER DO NOT START"

Switch lockouts for comminutor controls, etc.

DRY WELL

- Vent fan shall be started before entering the pumping station and left operating continuously while the operator is in the station.
- "DANGER PUMPS ON AUTOMATIC CONTROLLER" signs should be posted at the control panel floor level, and the pump floor level.
- "NO SMOKING" signs should be posed at the pump floor level.
- Lock out switches at control panel when working on any pump at any floor level.

WET WELL

- Start vent fan if available before entering and keep it in constant operation while operator is in the area.
- Use only waterproof and explosion proof extension cord lights.
- Do not enter a wet well if there are strong odours present. If it is not possible to exhaust the gases with the vent fan, check the well with an explosion meter. If a .2(or 20%) reading is recorded then self-contained air packs must be worn.
- Safety harness and rope must be worn by operators when cleaning the wet well or servicing pump controls.
- Entry into any wet well, sewer, or underground room having no mechanical ventilation system will be done in accordance with the Industrial Safety Act, Section 12, Subsection 2 and shall be recorded in the daily log as a 12-2 entrance.
- If a comminuting device located in the wet well requires servicing, the electrical disconnect shall be locked out and the key carried in the operator's pocket.

- When maintenance work or cleanout is required in the wet well of a pumping station in care of an operator of a one man plant, the operator must enlist the aid of another man, to stand by for emergencies above while he is in the wet well.

FIRE EXTINGUISHERS

The approximate operating time for CO_2 fire extinguishers is as follows:

$2\frac{1}{2}$ lb. 10 sec. $\pm$ 2 sec. 2. BC.

5 lbs. 14 sec. $\pm$ 2 sec. 4. BC.

10 lb. 14 sec. $\pm$ 3 sec. 6. BC.

15 lb. 25 sec. $\pm$ 4 sec. 8. BC.

20 lb. 30 sec. $\pm$ 4 sec. 8. BC.

The 2. BC etc., refers to the type of fires and area the extinguisher covers.

(BC) indicates electrical, gas, oil type fires, "A" type are wood, paper, etc., CO_2 will not be effective on "A" type fires.

(2) indicates the extinguisher will put out a fire of not more than 2 square feet in area.

Weight indicated refers to contents only.

Laboratory

ITEMS REQUIRED

Protective clothing

Separate marked container for broken glass

First aid kit

SAFETY HINTS

- Laboratory glassware must not be used for food.
- Practise good housekeeping. Keep all unnecessary equipment out of working areas.
- Areas around sinks and taps should be kept clear. You never know when you will have to wash chemicals off your hands quickly.
- Wipe up all spills immediately.
- All reagent bottles must be clearly labelled so they can be identified. The date when the reagent was made up, or received, should be on the label since some chemicals, particularly nitrogen compounds, become unstable with age.
- When diluting concentrated acids or bases, always add slowly to the water allowing time to cool. Use only heat resistant (Pyrex) glassware. When diluting sulphuric acid or when making up a solution of sodium hydroxide, cool the solution in a water bath.
- Chromic acid cleaning solution is a mixture of sodium or potassium dichromate in concentrated sulphuric acid. It dehydrates and oxidizes most organic matter, including clothing. **Treat it with care!**
- Use water as a lubricant when making glass to hose connections. For vinyl tubing, hot water can be used to make the plastic more pliable. Gloves should be worn when making hose connections to glass tubing.
- Suction bulbs should be used on all pipets. A valved type sold as a "PROPIPET" will save fumbling.
- Combining chemicals found in your laboratory can produce unexpected and unpleasant reactions.
- When disposing of any chemical in the sink, dilute with plenty of water.
- Bottles of hazardous liquids should be stored near floor level in ventilated cupboards.

- A thorough knowledge of first aid for dealing with lab accidents is essential. Know the relevant sections of the antidote chart.

- HASTE MAKES WASTE (and accidents). Planning can save far more time than hurrying (and produces fewer mistakes).

Precautions for Electrical Maintenance

- Plan safety into each job. Orderliness and good housekeeping are essential for your safety and the safety of others.
- Each employee shall be qualified both in experience and general knowledge to perform the particular work which he is assigned.
- Study the job carefully to determine all of the hazards present and to see that all necessary safeguards and safety devices are provided for safe working conditions.
- Examine all safety devices before they are used to ensure that they are in good condition.
- In all cases where work is being performed on or close to live conductors or equipment, at least two men shall work together. When it is necessary for one to leave, the other workman shall not continue the work until the first man returns.
- Consider the results of each action. There is no reason for you to take chances that will endanger yourself and to others.
- Satisfy yourself you are working under safe conditions. The care exercised by others can not be relied upon.
- Wear close fitting clothing, keep sleeves rolled down, avoid wearing unnecessary articles while working on or close to live circuits or apparatus.
- Use only approved types of rubber or leather gloves.
- Protect yourself by placing an insulated medium between you and ground or grounded apparatus to keep any part of your body from providing a path for electrical current when working on conductors or apparatus that may be energized.
- Use rubber mats when working on any electrical control panel or switch and disconnect boxes.

- Open and close switches completely with a firm positive motion. Switches in a partly open position may arc or cause a flash-over with damaging results to the switch and possible injuries to the operator.

- Open switches fully before removing fuses. To remove a fuse from a circuit carrying a current without opening the switch is particularly hazardous. Use an approved low-voltage fuse puller to remove fuses on a circuit of less than 500 volts (where no switch is provided) whether a disconnect is provided or not. Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuse in the cold terminal first.

- Shut off the power when examining or making repairs or alterations on light and power circuits. When this is impractical Head Office must be contacted for further instructions before proceeding with the work.

- Consider all electrical circuits to be dangerous. Treat dead circuits as though they were alive. This may prevent an accident as the circuit may be closed through an error of some other person.

- Exercise extreme care when required to locate troubles on a series lamp circuit, before repairs are made make sure the power is cut off.

- Lock or block open the control devices, open disconnect switches or remove fuses before examining, repairing or working on power circuits. After these precautions have been taken, attach tie-up tags worded "WORKMEN ARE WORKING ON LINE." The tag shall bear the name of the workman. Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. If the workman leaves without removing his tag it may be removed only on authorization of Head Office.

- Before working on line circuits at a point remote from the control switch, which has been tagged, it is recommended that the conductors be grounded at a point on the line between the switch and the work station.

- Make a complete check of the circuit before applying power for the first time. This is to be done by a qualified man in charge of the repairs, all other workmen to stand off at a safe distance.

NOXIOUS GASES, VAPOURS ETC.

A noxious gas or vapour is one that is directly or indirectly injurious or destructive to the health and life of a human being.

They can cause explosions, asphyxiation and some are poisonous. Non-poisonous gases can asphyxiate by displacing or excluding existing oxygen in confined areas.

How is a noxious gas detected in an area? and what type of gas or gases would it likely be ?

First, let us talk about entering a sewer manhole or any confined space that contains or has contained sewage that carry organic compounds or a tank where sludge is or has been stored.

Before entering these places it is necessary to test the air in the place to see if it is safe for men to enter for any reason or length of time. The person doing the testing shall be known as the testor.

In shallow manholes or tanks the air can be tested by lowering the probe of a gas sniffer through the holes in the manhole covers or through the open manhole of the tank.

In deeper manholes and tanks say of 10 ft. to 20 ft. deep or very large tanks it would be necessary to go down into the tank or manhole to get proper readings.

The testor then would be required to wear self-contained breathing apparatus and a safety harness and rope, while testing the air conditions in the manhole or tank.

CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TREATMENT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR-1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER LIMIT	UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO_2	COLORLESS, ODORLESS WHEN BREATHED IN LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS AN OXYGEN DEFICIENCY EXISTS.	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN, EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	-	-	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%	0.04	0.01	12.5	70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C_5H_{12} TO C_9H_{20}	COLORLESS, ODOR NOTICEABLE AT 0.03%. FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3	6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H_2	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0	74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

CHARACTERISTICS OF DANGEROUS GASES (CONT'D.)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER LIMIT	UPPER LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H_2S	ROTTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.01% IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.2% EXPOSURE TO 0.07 TO 0.1% RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02 TO 0.03	0.002	4.3	46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED AND HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS. FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH_4	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE.	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.		5.0	15.0	AT TOP, INCREASING TO CERTAIN DEPTH.	NATURAL GAS, SLUDGE GAS MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N_2	COLORLESS, TASTELESS. NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT.	-	-	-	-	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O_2	COLORLESS, ODORLESS,	1.11	NORMAL AIR CONTAINS 20.93% OF O_2. MAN CAN TOLERATE DOWN TO 12% MIN SAFE 8-HR EXPOSURE, 14 TO 16%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	-	-	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM POOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.	-	5.3	19.3	NEAR TOP OF STRUCTURE.	FROM DIGESTION OF SLUDGE.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

Gas	Chemical Formula	B.T.U. Calorific Valve	Specific Gravity or Vapour Density	Explosive Limits in air % by volume		Theoretical air required for complete combustion	Minimum Ignition Temperature °Fahrenheit	Maximum Flame Temperature °Fahrenheit	Flame Speed Per Sec.	Auto Ignition Temperature
				Lower	Upper					
Methane	CH_4	913.1	0.55	5	15	9.56 to 1	1170°	3484°	0.85	1000
Natural gas		1027	0.6	4.9	15	10.00 to 1	1170°	3562°	0.99	1000
Propane	C_3H_8	2385	1.52	2.10	10.10	23.9 to 1	898°	3573°	0.95	871

Taken from Factory Mutual's Handbook of Industrial Loss Prevention.

Chapter 37

Chart No. 2

GLOSSARY

The following definitions are intended as aids in the study of this manual, and define the terms only as they are used in the manual.

DO NOT use this glossary in place of a dictionary.

abraded: *Worn down or eroded.*
abrasion: *A wearing, grinding, or rubbing away by friction.*
absorb: *To take in, like a sponge.*
activated sludge: *Sewage that has been aerated to encourage the growth of organisms that decompose organic matter.*
adsorb: *To hold on the surface; stick on.*
aeration: *Adding air to liquid by mechanical means.*
aerobic: *Requiring oxygen.*
agglomerate: *To gather suspended matter into larger masses which settle rapidly.*
algae: *Tiny plants, usually living in water and often green.*
alkaline: *A condition which will raise the pH in water or wastewater higher than 7.*
alum: *Aluminum sulfate; used in sewage treatment to remove phosphorus. Also used in water treatment as a coagulant.*
aluminum: *A metallic element, always occurring in combined form.*
ammonia: *A chemical combination of hydrogen and nitrogen.*
anaerobic: *Requiring the* absence *of oxygen.*
appurtenances: *Attachments; related equipment or components.*
bacteria: *Single-celled microscopic plants living in soil, water, organic matter, or the bodies of plants and animals.*
bacteriological: *Dealing with bacteria and their relation to water and sewage treatment.*
bacteriology: *The study of bacteria.*
baffle: *A device to turn aside, check, or regulate flow.*
Barminutor: *Trade name for a shredding device.*
bar screen: *A rack made of parallel bars for removing coarse materials in the wastewater passing between them.*
Biochemical Oxygen Demand: *See* BOD.
biological: *Relating to organisms and their life processes.*
BOD: *Biochemical Oxygen Demand. A measure of the oxygen used in decomposing organic matter.*
BOD_5: *The amount of oxygen used in decomposing organic matter measured over a period of 5 days.*
buoyancy: *The ability to float or rise up in a liquid.*

calcium: *A metallic element found only in combined form.*

capacity: *The exact amount that can be held; the exact rate of flow that can be carried; the load for which a machine, plant, or system is designed.*

carbohydrates: *One of the principle groups of food used by bacteria and higher organisms in the decomposition of organic matter.*

carbon dioxide: *A gas composed of carbon and oxygen.*

centrate: *Liquid effluent from a centrifuge.*

centrifugal separator: *Centrifuge.*

centrifuge: *A machine that separates solids from wastewater in a spinning motion.*

channel: *A natural or man-made waterway with a definite bed and sides to confine the water as it moves.*

chlorination: *The application of chlorine to water and wastewater.*

chlorine: *A greenish-yellow gas that can be compressed to an amber liquid and is usually used in water and wastewater treatment as a disinfectant.*

chlorine contact chamber: *A basin in which liquid is put in contact with chlorine.*

chlorine demand: *The difference between the amount of chlorine added to a water or wastewater and the amount of chlorine residual left after a certain length of time.*

CPRV: *Chlorine Pressure Reducing Valve.*

clarifier: *Sedimentation tank.*

CO_2: *See* carbon dioxide.

coagulants: *In water and wastewater, chemicals used to thicken finely divided suspended solids into groups for easy removal.*

coagulation: *Thickening colloidal solids for easy removal by the addition of chemicals or biological processes.*

coefficient: *A number that serves as a measure of some property or characteristic.*

collection system: *System of piping, including pumps and other associated equipment, for collecting and carrying wastewater to a treatment plant or receiving stream.*

colloidal solids: *Finely divided suspended solids which will not settle out and cannot be seen with the naked eye.*

combustion: *The act of burning.*

Comminutor: *A shredding device.*

component: *A unit of machinery; also, a part of something.*

compound: *The combination of two or more elements.*

concrete number: *Whole number; not a fraction.*

contaminant: *An undesirable or unwholesome element that makes water unfit to use; pollutant.*

conventional: *Traditional; the usual.*

cross flight: *Wooden scraper for moving sludge and scum in a rectangular clarifier.*

cu.yd./a/yr.: *Cubic yard per acre per year.*

debris: *The remains of something broken down or destroyed.*

decant: *To draw or pour off without disturbing the sediment or the lower liquid layers.*

decomposition: *The chemical or biological breakdown of materials.*

detention time: *The length of time that wastewater is held in a unit for treatment.*

deterioration: *The state of having grown worse in quality.*

detritus: *Heavy minerals such as grit, and other coarse debris carried in water and wastewater.*

dewater: *To remove water.*

diffuse: *Scatter or distribute evenly.*

diffuser: *A device for distributing tiny air bubbles throughout a liquid, such as wastewater.*

digested sludge: *Sludge that has undergone decomposition to a relatively stable point.*

digester: *The tank in which the biological decomposition of sludge occurs and gas is produced.*

digestion: *The biological decomposition of organic matter to a more stable form.*

dilute: *To make thinner or weaker by adding liquid.*

dissolved solids: *In sewage treatment, suspended solids that are not easily seen.*

effluent: *Flowing out; a liquid comming out of a tank, treatment plant, etc.*

elutriate: *To purify, separate, or remove by washing.*

emulsify: *To mix two or more immiscible liquids (such as oil and water) into a state of suspension, one in the other, by agitation or chemical agents.*

enzyme: *A protein that starts a chemical reaction, enabling it to continue at body temperature.*

fat: *One of the principal groups of food used by bacteria and higher organisms in the decomposition of organic matter.*

fertilizer: *A combination of nutrients that promotes the growth of organisms.*

filtrate: *The liquid which has passed through a filter.*
filtration: *The process of passing a liquid through a filter to remove suspended solids.*
final effluent: *The water leaving the final treatment unit of a water or wastewater treatment plant; plant effluent.*
fine screen: *Usually a rack in pretreatment which has spaces of about an inch or less between its bars.*
flights: *Wooden scrapers mounted on parallel chains to move sludge to a hopper at the end of a rectangular clarifier.*
floc: *Small jelly-like masses formed in a liquid by adding a coagulant.*
flocculation: *The collection of coagulated suspended solids into a mass by gentle stirring.*
flotation: *The raising of suspended matter to the surface of wastewater in a tank for removal by skimming.*
flow: *The movement of a liquid from place to place.*
fluctuate: *To shift back and forth uncertainly; to ebb and flow in waves.*
garbage: *The animal and vegetable wastes from handling, preparing, and serving food.*
gpcd: *Gallons per capita (person) per day.*
grinding: *A process used to make coarse materials in wastewater small enough to pass through screens into treatment without damaging equipment.*
grit: *The heavy mineral matter present in wastewater, such as sand, gravel, cinders.*
H_2S: *See* Hydrogen Sulphide.
hard water: *Water containing various elements that cause soap to curdle, scaling, and sometimes damage in some industrial process; sometimes it also has an unpleasant taste.*
headloss: *Reduction in the speed of flow.*
heat exchanger: *A device for transferring heat from a fluid flowing in piping to another fluid outside the piping or vice versa.*
hydrant: *A piece of equipment connected to a water main and used to discharge water at a high rate through a fire hose.*
hydraulic: *Operated, moved, or effected by water or other liquids.*
hydraulic load: *The total amount of sewage reaching a treatment plant.*
hydrogen sulphide: *A gas composed of hydrogen and sulphur ("rotten egg" gas).*
hydrolyze: *to liquefy.*

hydrostatic: *Relating to the pressure in a liquid or to the liquid when at rest.*
Imhoff tank: *A wastewater treatment tank with two chambers for sedimentation and sludge digestion.*
incineration: *Burning to ashes; a method of sludge disposal.*
inert: *Non-acting; having no chemical or biological action.*
infiltration: *In sewage treatment, leakage of groundwater into pipes through joints, porous walls, or breaks.*
influent: *Water or wastewater flowing into a treatment plant or any of its units.*
inlet: *Upstream opening to allow water or wastewater to flow in.*
inorganic: *Made of matter that does not come from plant or animal life.*
insoluble: *Unable to dissolve in liquid.*
invert: *Turn upside-down; also, the floor or lowest part of the inside of a closed conduit.*
lagoon: *A pond used to stabilize wastewater.*
landfill site: *An area used for the disposal of waste by burying it between layers of earth.*
lethal: *Deadly.*
lime: *A chemical, usually calcium hydroxide, sometimes used for controlling pH values in digesters.*
maintenance: *The upkeep necessary for efficient operation; also lubrication, replacing worn or broken parts, etc.*
malfunction: *Failure to operate in the normal or usual manner.*
manually: *Using the hands (hand-operated instead of automatically).*
metabolize: *To perform the chemical changes in organic cells, providing energy for growth and activity.*
methane: *Gas produced by the decomposition of organic matter.*
mg/l: *Milligrams per litre.*
microbial: *Referring to an organism of microscopic size.*
microorganism: *A tiny organism invisible (or barely visible) without a microscope.*
microscope: *An instrument to magnify objects too small to be seen with the naked eye.*
millilitre: *One thousandth of a litre.*
mixed liquor: *A mixture of activated sludge and organic matter in the aeration tank.*
ml: *Millilitre.*
MLSS: *Mixed Liquor Suspended Solids.*
municipality: *An organized area, such as a township, city, village, etc.*

nitrogen: *A gaseous element occurring in sewage and used as a food by organisms decomposing organic matter.*

nutrient: *Food for the growth of organisms.*

objectionable: *Offensive; disagreeable; undesirable.*

optimum: *The ideal, or most favourable, condition.*

organic: *Relating to living organisms; made of matter that is plant or animal.*

organisms: *In water and wastewater treatment, bacteria.*

orthotolidine: *A chemical used to determine the residual chlorine in water.*

outlet: *Downstream opening or discharge end of a pipe, culvert, or canal.*

oxidation: *The act of combining with oxygen; any reaction which involves the loss of electrons from an atom.*

parallel: *Going in the same direction while remaining equally distant from each other and not meeting.*

Parshall Flume: *A device used to measure liquid flow in a channel.*

periphery: *The outside boundary.*

permeable: *Having pores or openings that allow water to pass through.*

pH: *The condition of the acid/alkaline balance, expressed on a scale of 0 to 14, with 7 being neutral, 7 to 0 increasing acidity, and 7 to 14 increasing alkalinity.*

phosphorus: *A nonmetallic element of the nitrogen family.*

physiological: *Relating to the normal functions of an organism.*

plant effluent: *See* Final effluent.

pollutant: *Something that contaminates, especially man-made wastes.*

ppm: *parts per million.*

preaeration: *A method of preparing wastewater for treatment by aeration to remove gases, add oxygen, float grease, etc.*

precipitation: *The act of forming a deposit from a substance in solution; also, a deposit on the earth of rain, snow, hail.*

primary: *First.*

proportional: *Have a constant relationship in amount or size to one or more things.*

protein: *One of the principal groups of food required by bacteria and higher organisms in the decomposition of organic matter.*

protoplasm: *The only form of matter in which life can be found; the living part of an organic cell.*

PRV: *Pressure Relief Valve.*

pump: *A mechanical device for raising, transferring, or compressing fluids or thinning gases.*

putrescible: *liable to decay or rot.*

quiescent: *Not active; being at rest.*

raw sewage: *Untreated wastewater.*

raw sludge: *Settled, undigested sludge from sedimentation tanks.*

reaeration: *The process of adding air to a wastewater that is low in oxygen.*

receiving waters: *Natural lakes, streams, oceans, etc., that receive treated or untreated wastewater.*

retention: *The act of holding back.*

Rotogrator: *A shredding device.*

rural: *Relating to the country, or farm, areas.*

sanitary sewage: *The combined wastewaters from homes, industries and commercial establishments.*

sanitary sewer: *A sewer that carries wastewater from homes, shopping centres, industries and institutions, along with some ground, storm, and surface waters.*

schematic: *A graphic sketch or outline; a diagram.*

screen: *Used to remove coarse materials in water and wastewater to prevent them from entering intakes to treatment plants.*

screenings: *Material removed from water and wastewater by screens.*

scum: *Suspended solids that rise to the surface of a liquid and form a layer or film.*

scum blanket: *A thick mass of suspended solids floating on wastewater.*

secondary: *Follows primary.*

sedimentation: *Settling or clarification; the process of allowing solids in water and sewage to sink to the bottom for easy removal.*

sedimentation tank: *A tank or basin for holding water or waste-water to settle out the solids.*

seed sludge: *Well-digested sludge used to start digestion processes.*

septic: *Decayed, rotten, infected.*

settleable solids: *The material in wastewater that either settles to the bottom or floats to the top after a certain time.*

sewage: *The spent water of a community; wastewater.*

sewage strength: *The amount of suspended solids and organic matter present in the sewage.*

sewerage system: *Piping and attachments used to collect and carry wastewater.*

shock load: *A higher rate of flow or sewage strength than the treatment plant is able to handle.*

short-circuiting: *A hydraulic condition occurring in parts of a tank where the time of travel is less than the flow-through time.*

skimming: *The process of removing floating grease or scum from the surface of wastewater in a tank.*

skimmings: *Grease, solids, liquids and scum removed from the surface of wastewater.*

sludge: *Settled solids produced by wastewater treatment.*

sludge bank: *A buildup of wastewater solids in waterways or open water.*

sludge blanket: *A buildup of sludge forming a layer in wastewater.*

sludge drying bed: *An area made up of layered rock, gravel, and sand, or other porous material, on which digested sludge is spread to dry by drainage and evaporation.*

soft water: *Water having low concentrations of calcium and magnesium salts, making it easy to lather soap.*

soluble: *Able to dissolve in liquid.*

stable: *The point at which wastewater, chemicals or digested sludge will no longer change in composition.*

storm water: *The water that runs off the surface of a drainage area during and right after a rainfall.*

subnatant: *Liquid coming from the drains of sludge drying beds.*

sump: *A tank or pit into which liquids are drained and held until pumped or discharged out again.*

supernatant: *The liquid standing above a sediment; in sludge digestion, the liquid standing between the sludge at the bottom and the scum at the top.*

surcharge: *An excessive load or burden; an extra tax or charge.*

sulphur: *A nonmetallic element.*

surface water: *All water found on the surface of the earth.*

suspended solids: *Material which can be seen in the sewage and settled or filtered out.*

tangential: *Touching; going away from the centre.*

tank: *Any man-made container used to hold liquids for treatment.*

tertiary: *Third; follows secondary.*

total solids: *All the solids contained in sewage.*

toxic: *Poisonous.*

trash rack: *A grid or screen placed across a waterway to catch floating debris.*

trickling filter: *Used to clarify and oxidize wastewater, and*

made up of coarse materials, such as broken stones.

turbidity: *A condition in water caused by suspended matter; murkiness.*

undulating: *Forming or moving in waves.*

vacuum filter: *A filter made of a drum covered with filter cloth and lying on its side partially submerged in liquid. As it revolves, a vacuum sucks the liquid through the cloth, leaving the solid matter to be scraped off continuously.*

valve: *A device in a pipeline for controlling the amount and direction of a flow.*

velocity: *Speed.*

vertical: *Upright; rising straight up.*

volatile: *Able to evaporate at fairly low temperatures.*

volatile matter: *Organic material that burns readily.*

volume: *Amount; quantity; also, available space, as in "the* volume *of a tank".*

waste stabilization pond: *Wastewater lagoon.*

weir: *A dam or enclosure in water or wastewater used to raise the water level or change the direction of its flow; with notches or a crest, it measures the flow.*